Commodore 64 Assembly Language

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Bruce Smith

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Preface

At the centre of your Commodore 64 microcomputer is the 6510 microprocessor which is responsible for coordinating and controlling every single thing your Commodore 64 does while it is switched on. The microprocessor can be programmed in its own language—machine language—and that is the aim of this book, to teach you just how to program your micro at its very own machine level.

The text assumes that you have some knowledge of CBM BASIC but know absolutely nothing about machine code. I have tried very hard to write in a non-technical language and to set the chapters out in a logical manner, introducing new concepts in digestible pieces as and when they are needed, rather than devoting chapters to specific items. Wherever possible practical programs are included to bring home the point being made, and in most instances these are analysed and the function and operation of each instruction explained.

Commodore 64 Assembly Language is completely self-contained, includes a full description of all the machine code instructions available and suggests suitable applications for their use. After a 'bit of theory' in the opening chapters, the main registers of the 6510 are introduced and descriptions given of how, when and where machine code routines can be entered. There is also a simple machine code monitor program to facilitate the entry of such routines.

After discussing the way in which the 6510 flags certain conditions to the outside world, some of the modes of addressing the chip are described. Machine code addition and subtraction are introduced and the easiest ways of manipulating and saving data for future use by the program and processor are described. Machine code loops (equivalent to BASIC's FOR . . . NEXT . . . STEP) show how sections of code may be repeated, and subroutines and jumps take the place of BASIC's GOSUB and GOTO. Also included is a look at some of the more complicated procedures such as multiplication and division using the shift and rotate instructions, and producing sprites in machine code illustrates just how fast real time graphics can be!

The Kernal is a very important part of the Commodore's set-up, so no expense has been spared in explaining every Kernal routine in detail. Practical examples show how the more important ones can be used.

Finally, a comprehensive set of appendices provide a quick and easy reference to the sorts of things you'll need to 'want to know quickly' when you start writing your very own original machine code programs!

Highbury, February 1984 — Bruce Smith

DEDICATION

To Christie,
Para sa paburito kung Pamankin.

1 Machine Code or Assembly Language

The 6510 microprocessor within your Commodore 64 microcomputer can perform 152 different operations, with each one being defined by a number (or *operation code*) in the range 0 to 255. To create a machine code program we need simply to POKE successive memory locations with the relevant operation codes—'opcodes' for short. For example, to store the value 5 at location 1500 (in other words to do the machine code equivalent of BASIC's POKE 1500,5) we would need to POKE the following bytes into memory:

```
169
  5
141
220
  5
```

and then ask the Commodore's 6510 to execute them. Not exactly clear is it! That's where *assembly language* comes in.

Assembly language allows us to write machine code in an abbreviated form which is designed to represent the actual operation the opcode will perform. This abbreviated form is known as a *mnemonic* and it is the basic building block of assembly language (or assembler) programs.

We could rewrite the previous machine code in assembler like this:

```
LDA #5
STA 1500
```

and it can be read as:

Loa**d** the **a**ccumulator with the value 5

Store the **a**ccumulator's contents at location 1500

As you can see from the **bold** letters, the mnemonic is composed of letters in the instruction, which greatly enhances its readability.

Once the assembler program is complete, it can be converted into machine code in one of two ways.

1. With the aid of a *mnemonic assembler.* This is itself a program (written in machine code or BASIC) which transforms the assembly language instructions (known as the source) into machine code (known as the object code) and POKEs them into memory as it does so.

2. By,looking up the relative codes in a table and then POKEing them into memory using a monitor program or a DATA-reading FOR. . .NEXT loop. Full details of this method are given in Chapter 6, which also includes a simple monitor program.

All the programs in this book are listed in their DATA statement, machine code *and* assembler forms, so they can be entered by any of the above methods—simply extract the information you require.

Appendix 3 provides comprehensive user information about *all* of the 651Ø's opcodes, so don't worry too much if some of this seems a bit foreign at the moment—we'll soon change that!

WHY MACHINE CODE?

A question often asked is, "Why bother to program in machine code at all?" Well, one reason might be that you're fed up with BASIC and want to broaden your horizons, but, from the practical point of view there are two main reasons for programming in machine code.

Firstly speed. Machine code is executed very much faster than an interpreted high level language such as CBM BASIC. Remember that the BASIC interpreter is itself written in machine code, and that the BASIC statements and commands are simply pointers to the machine code routines in the ROM which actualy carry out the specified functions. It is because each statement and command must first be identified and located within the ROM that a decrease in operational speed occurs. Secondly, learning machine code allows you to understand just how your computer works, and lets you create special effects and routines not possible within the constraints imposed by the limited set of BASIC instructions. Machine code allows you to control your Commodore 64 rather than it controlling you!

2 Numbers

BINARY, HEX AND DECIMAL

We have seen that the instructions the Commodore 64 operates with consist of sequences of numbers. But just how are these numbers stored internally? Well, not wishing to baffle you with the wonders of modern computer science, let's try to simplify matters somewhat and say that each instruction is stored internally as a binary number. Decimal numbers are composed of combinations of ten different digits, that is 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9 and are said to work to a *base* of 10. As its name suggests, binary numbers work to a base of 2 where only the digits 0 and 1 are available. These two numbers represent the two different electrical conditions that are available inside the Commodore 64, namely 0 volts (off) and 5 volts (on).

The machine code described in Chapter 1 is therefore represented internally as:

Mnemonic	Machine code	Binary
LDA	169	10101001
$5	05	00000101
STA	141	10001101
00	00	00000000
$15	15	00010101

As can be seen, each machine code instruction is expressed as eight binary digits, called *bits*, which are collectively termed a *byte*.

Usually each of the bits in a byte is numbered for convenience as follows:

7	6	5	4	3	2	1	0

The number of the bit increases from right to left, but this is not so odd as it may first seem.

Consider the decimal number 2934, we read this as two thousand, nine hundred and thirty four. The highest numerical value, two thousand, is on the left, whilst the lowest, four, is on the right. We can see from this that the position of the digit in the number is very important, as it will affect its *weight*.

The second row of Table 2.1 introduces a new numerical representation. Each base value is postfixed with a small number or *power*, which corresponds to its overall position in the number. Thus 10^3, read as ten raised to the power of three, simply implies $10 \times 10 \times 10 = 1000$.

Table 2.1

Value	1000s	100s	10s	1s
Representation	10^3	10^2	10^1	10^0
Digit	2	9	3	4

In binary representation, the weight of each bit is calculated by raising the base value, two, to the bit position (see Table 2.2). For example bit number 7 has a notational representation of 2^7 which expands to: $2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 128$!

Table 2.2

Bit number	7	6	5	4	3	2	1	0
Representation	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Weight	128	64	32	16	8	4	2	1

BINARY TO DECIMAL CONVERSION

As it is possible to calculate the weight of individual bits, it is a simple matter to convert binary numbers into decimal numbers. The rules for conversion are:

If the bit is *set*—that is it contains a 1—add its weight
If the bit is *clear*—that is it contains a 0—ignore its weight

Let us try an example and convert the binary number 10101010 into its equivalent decimal value.

$1 \times 128(2^7) = 128$

$0 \times 64(2^6) = 0$

$1 \times 32(2^5) = 32$

$0 \times 16(2^4) = 0$

$1 \times 8(2^3) = 8$

$0 \times 4(2^2) = 0$

$1 \times 2(2^1) = 2$

$0 \times 1(2^0) = 0$

170

Therefore 10101010 binary is 170 decimal.

Similarly 11101110 represents:

$$
\begin{aligned}
1 \times 128(2^7) &= 128 \\
1 \times 64(2^6) &= 64 \\
1 \times 32(2^5) &= 32 \\
0 \times 16(2^4) &= 0 \\
1 \times 8(2^3) &= 8 \\
1 \times 4(2^2) &= 4 \\
1 \times 2(2^1) &= 2 \\
0 \times 1(2^0) &= 0 \\
\hline
&\quad 238
\end{aligned}
$$

in decimal.

DECIMAL TO BINARY CONVERSION

To convert a decimal number into a binary one, the procedure described earlier is reversed—each binary weight is subtracted in turn. If the subtraction is possible, a 1 is placed into the binary column and the remainder carried down to the next row where the next binary weight is subtracted.

If the subtraction is not possible, a 0 is placed in the binary column and the number moved down to the next row. For example, the decimal number 141 is converted into binary as in Table 2.3.

Table 2.3

Decimal number	Binary weight	Binary	Remainder
141	$128(2^7)$	1	13
13	$64(2^6)$	0	13
13	$32(2^5)$	0	13
13	$16(2^4)$	0	13
13	$8(2^3)$	1	5
5	$4(2^2)$	1	1
1	$2(2^1)$	0	1
1	$1(2^0)$	1	0

Therefore 141 = 10001101 binary.

BINARY TO HEX CONVERSION

Although binary notation is probably as close as we can come to representing the way numbers are stored within the Commodore 64, you will no doubt have noticed that the machine code examples include some groups of two characters preceded by a dollar sign, '$'. This type of number is known as a hexadecimal number, or hex for short, and its value is calculated to a base of 16! This, at first sight, may seem singularly awkward, however it does present several distinct advantages over binary and decimal numbers as we shall see.

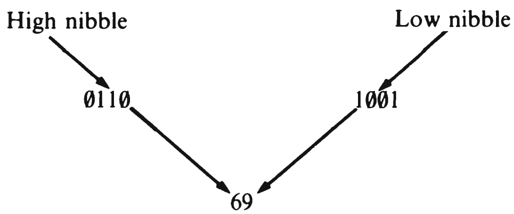
Sixteen different characters are required to represent all the possible digits in a hex number. To produce these, the numbers 0 to 9 are retained, and the letters A, B, C, D, E and F are used to denote the values 10 to 15. Binary conversion values are shown in Table 2.4.

Table 2.4

Decimal	Hex	Binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

To convert a binary number into hex, the byte must be separated into two sets of four bits, termed *nibbles,* and the corresponding hex value of each nibble extracted from Table 2.4.

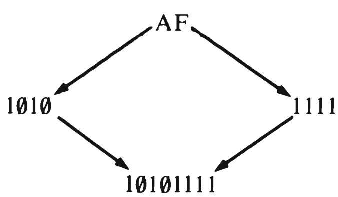
Example Convert 0110 1001 to hex:



Because it is not always apparent whether a number is hex or decimal (as in the example above), hex numbers on the Commodore are always preceded by a dollar sign—therefore 01101001 is $69 (read hex six nine).

By reversing the process, hex numbers can readily be converted into binary.

Example Convert $AF to binary:



It should now be apparent that hex numbers are much easier to convert to binary (and vice versa), than their decimal counterparts, and the maximum binary number possible with one byte, 11111111, requires just two hex digits, $FF.

HEX TO DECIMAL CONVERSION

For the sake of completeness, let's see how hex and decimal numbers may be converted. To transform a hex number into decimal, the decimal weight of each digit should be summed.

Example convert $31A to decimal:

The 3 has the value $3 \times 16^2 = 3 \times 16 \times 16 = 768$

The 1 has the value $1 \times 16^1 = 1 \times 16 = 16$

The A has the value 1×16^0 = 1Ø × 1 = 1Ø

add these together to give $31A = 794 decimal.

Converting decimal to hex is a bit more involved and requires the number to be repeatedly divided by 16 until a value less than 16 is obtained. This hex value is noted, and the remainder carried forward for further division. This process is continued until the remainder itself is less than 16.

Example convert 4Ø72 to hex:

4Ø72 ÷ 16 ÷ 16 = 15 = F (remainder = 4Ø72 − (15 × 16 × 16) = 232)

232 ÷ 16 = 14 = E (remainder = 232 − (14 × 16) = 8)

8 = 8

Therefore 4Ø72 decimal is $FE8.

Both of these conversions are a little long winded (to say the least!) and after all we do have a very sophisticated microcomputer available to us, so let's make it do some of this more tedious work!

3 It All Adds Up!

BINARY ARITHMETIC

Please don't be put off and skip this chapter simply because it contains that dreaded word—arithmetic. The addition and subtraction of binary numbers is simple, in fact if you can count to two you will have no problems whatsoever! Although it is not vital to be able to add and subtract ones and noughts by 'hand', this chapter will introduce several new concepts which are important, and will help you in your understanding of the next few chapters.

ADDITION

There are just four, simple, straightforward rules when it comes to adding binary numbers. They are:

1. Ø + Ø = Ø
2. 1 + Ø = 1
3. Ø + 1 = 1
4. 1 + 1 = (1)Ø

Note, that in rule 4, the result of 1 + 1 is (1)Ø. The 1 in brackets is called a *carry* bit, and its function is to denote an overflow from one column to another, remember, 1Ø binary is 2 decimal. The binary 'carry' bit is quite similar to the carry that can occur when adding two decimal numbers together whose result is greater than 9. For example, adding together 9 + 1 we obtain a result of 1Ø (ten), this was obtained by placing a zero in the units column and carrying the 'overflow' across to the next column to give: 9 + 1 = 1Ø. Similarly, in binary addition when the result is greater than 1, we take the carry bit across to add to the next column.

Let's try to apply these principles to add together two 4 bit binary numbers, Ø1Ø1 and Ø1ØØ.

```
  Ø1Ø1        ($5)
+ Ø1ØØ        ($4)
  ----
  1ØØ1        ($9)
```

Reading each individual column from right to left:

First column:	1 + Ø	= 1
Second column:	Ø + Ø	= Ø
Third column:	1 + 1	= Ø (1)
Fourth column:	Ø + Ø = Ø + (1)	= 1

In this example a carry bit was generated in the third column, and was carried across and added to the fourth column.

Adding 8 bit numbers is accomplished in a similar manner:

```
  01010101      ($55)
+ 01110010      ($72)
  --------
  11000111      ($C7)
```

SUBTRACTION

So far we have been dealing with positive numbers, however in the subtraction of binary numbers we need to be able to represent negative numbers as well as positive ones. In binary subtraction though, a slightly different technique from normal everyday subtraction is used, in fact we don't really perform a subtraction at all—we add the negative value of the number to be subtracted. For example, instead of executing 4 − 3 (four minus three) we actually execute 4 + (−3) (four, plus minus three)! Figure 3.1 will hopefully eradicate any confusion or headaches that may be prevailing!

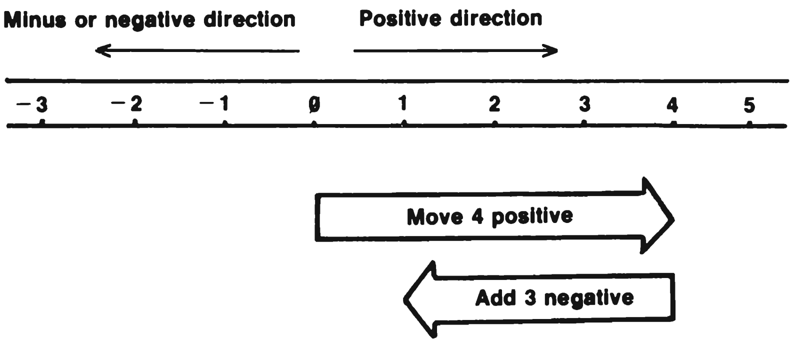


Figure 3.1 Diagramatic representation of 4 + (− 3).

We can use the scale to perform the example 4 + (−3). The starting point is zero. First move to point 4 (i.e. four points in a positive direction) and *add* to this −3 (i.e. move three points in a negative direction). We are now positioned at point 1 which is, of course, where we should be. Try using this method to subtract 8 from 12, to get the principle clear in your mind.

Okay, lets now see how we apply this to binary numbers, but first, just how are negative numbers represented in binary? Well, a system known as *signed binary* is employed, where bit 7, known as the most significant bit (msb), is used to denote the *sign* of the number. Traditionally a '0' in bit 7 denotes a positive number and a '1' a negative number. For instance, in signed binary:

```
1 0000001
↑ └──┬──┘
|    └──Bits 0–6 give value = 1
|
└───────Sign bit = 1, therefore number is negative
```

so, 10000001 = −1. And:

```
0 1111111
↑ └──┬──┘
|    └──Bits 0–6 give value = 127
|
└───────Sign = 0 therefore number is positive
```

therefore 01111111 = 127.

However, just adjusting the value of bit 7 as required, is not an accurate way of representing negative numbers. What we must do to convert a number into its negative counterpart, is to obtain its *two's complement* value. To do this simply invert each bit and then add one.

To represent −3 in binary, first write the binary for 3:

```
0 0 0 0 0 0 1 1
```

Now invert each bit. (Replace each 0 with a 1, and each 1 with a 0—this is known as its *one's complement*.

```
1 1 1 1 1 1 0 0
```

Now add 1:

```
    1 1 1 1 1 1 0 0
+                 1
    ---------------
    1 1 1 1 1 1 0 1
```

Thus, the two's complement value of −3 = 11111101. Let us now apply this to our original sum 4 + (−3):

```
(4)              0 0 0 0 0 1 0 0
(−3)             1 1 1 1 1 1 0 1
                 ---------------
(Now add)     (1)0 0 0 0 0 0 0 1
```

We can see that the result is 1 as we would expect, but we have also generated a carry bit due to an overflow from bit 7. This carry bit can be ignored for our purposes at present, though it does have a certain importance as we shall see later on.

A further example may be of use. Perform 32 − 16 i.e. 32 + (−16).

32 in binary is:

```
0 0 1 0 0 0 0 0
```

16 in binary is:

```
0 0 0 1 0 0 0 0
```

The two's complement of 16 is:

```
    1 1 1 0 1 1 1 1
+                 1
    ---------------
    1 1 1 1 0 0 0 0
```

Now add the two together:

```
(32)            0 0 1 0 0 0 0 0
(−16)         + 1 1 1 1 0 0 0 0
                ---------------
(16)        (1) 0 0 0 1 0 0 0 0
```

Ignoring the carry, we have our result, 16.

We can see from these examples that, using the rules of binary addition, it is possible to add or subtract signed numbers. If the 'carry' is ignored, the result, including the sign, is correct. Thus it is also possible to add two negative values together and still obtain a correct negative result. Using two's complement signed binary let's perform (−2) + (−2).

2 in binary is:

```
0 0 0 0 0 0 1 0
```

The two's complement value is:

```
  11111101
+        1
  --------
  11111110
```

We can add this value twice to perform the addition:

```
(-2)         11111110
(-2)       + 11111110
             --------
          (1)11111100
```

Ignoring the carry, the final result is −4. You might like to confirm this by obtaining the two's complement value of −4 in the usual manner.

BINARY CODED DECIMAL (BCD)

So far we have been dealing with the binary representation of hexadecimal numbers, which is the normal way the Commodore 64 deals with its instructions and numbers. However, on certain occasions, such as when dealing with business applications, where it is essential to retain every significant digit in a result, it would be advantageous to work in a form of decimal binary where only the decimal digits 0 to 9 are available. Binary Coded Decimal, or BCD for short, allows us to do this. Table 3.1 shows the BCD-binary representations. As can be seen, only the binary values 0000 through to 1001 are required, and the combinations 1010 to 1111 are unused and are not legal values in BCD.

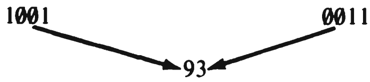
Table 3.1

BCD digit	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
not used	1010
not used	1011
not used	1100
not used	1101
not used	1110
not used	1111

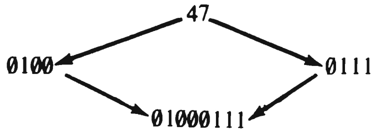
As only four binary bits are required to code any BCD digit, two BCD digits can be included in a single byte if required, this is known as *packed BCD.*

Converting BCD to binary and vice versa is performed as described in the previous hexadecimal examples; split the byte in half and convert each nibble separately.

Example convert 10010011 to BCD:



Example convert 47 BCD to binary:



We shall see how the Commodore distinguishes between BCD and normal hex binary in Chapter 7, but first some sums!

BCD ADDITION

We can now try adding two BCD binary values, consider 8 BCD + 4 BCD:

8 BCD	0 0 0 0 1 0 0 0
4 BCD	0 0 0 0 0 1 0 0
Adding together	0 0 0 0 1 1 0 0

We have obtained an illegal result, in fact we have obtained the 'binary' sum and not the 'BCD' sum. The result should of course be 12 BCD which is 0001 0010 in BCD binary. In order to reach the correct value, the redundant binary values (1010 to 1111) must be 'jumped over'. To do this 6 (or 0110 binary) must be added. Thus:

0 0 0 0 1 1 0 0	(binary result)
0 0 0 0 0 1 1 0	(BCD correction)
0 0 0 1 0 0 1 0	(result 12 BCD)

We can try another example which includes this decimal adjust—15 BCD + 10 BCD:

15 BCD	0 0 0 1 0 1 0 1	
10 BCD	0 0 0 1 0 0 0 0	
Binary result	0 0 1 0 0 1 0 1	= 25 BCD

In this example the correct result has been obtained without adding the decimal adjust. This is because the addition was such that it did not encounter any of the illegal BCD values. This means that when adding two BCD digits, the decimal adjust value need only be added if a nibble value *greater than* 9 occurs in the result.

BCD SUBTRACTION

BCD subtraction is not so much difficult as it is involved. It is performed along the lines of binary subtraction, but instead of adding the two's complement value of the negative number, you add its *ten's complement.* The best way to explain the process is by working through an example. Let's choose a simple subtraction first of all, 9 BCD − 4 BCD:

9 BCD	0 0 0 0 1 0 0 1
4 BCD	0 0 0 0 0 1 0 0

To find the one's complement of 4 BCD invert each bit:

```
1111 1011
```

and add one to obtain the ten's complement (and thus −4BCD):

```
1111 1011
        1
---------
1111 1100
```

Perform the subtraction by adding the two values:

```
 9 BCD        0000 1001
−4 BCD        1111 1100
           -------------
           (1)0000 0101
```

Ignore the carry to obtain the result: 5 BCD.

Simple so far, but what if we encounter something like 11 BCD − 5 BCD? Here adjustment will be necessary to take into account the six unused binary codes 1010 to 1111. Instead of adding the decimal adjustment, it must be subtracted.

```
11 BCD        0001 0001
−5 BCD        1111 1011
           -------------
           (1)0000 1100
```

Ignoring the carry, we now need to convert the illegal code to BCD by subtracting 6 (or rather adding its two's complement).

```
Binary result     0000 1100
−6                1111 1010
               -------------
              (1) 0000 0110
```

Result = 6 BCD, which is correct.

4 It's Logical

LOGICAL OPERATIONS

The theory of logic is based on situations where there can only ever be two possibilities, namely *yes* and *no*. In binary terms these two possibilities are represented as 1 and Ø.

There are three different logical operations that can be performed on binary numbers, they are AND, OR and EOR. In each case the logical operation is performed between the corresponding bits of two separate numbers.

AND

The four rules for AND are:

1. Ø AND Ø = Ø
2. 1 AND Ø = Ø
3. Ø AND 1 = Ø
4. 1 AND 1 = 1

As can clearly be seen, the AND operation will only generate a 1 if *both* of the corresponding bits being tested are 1. If a Ø exists in either of the corresponding bits being tested, the resulting bit will always be Ø.

Example AND the following two binary numbers:

```
      1 Ø 1 Ø
AND   Ø Ø 1 1
      -------
      Ø Ø 1 Ø
```

In the result only bit 1 is set, the other bits are all clear because in each case one of the bits being tested contains a Ø.

The main use of the AND operation is to 'mask' or 'preserve' certain bits. Imagine that we wish to preserve the low four bits of a byte (low nibble) and completely clear the high four bits (high nibble). We would need to AND the number with ØØØØ1111. If the other byte contained 1Ø1Ø11ØØ the result would be given by:

```
      1 Ø 1 Ø 1 1 Ø Ø      (byte being tested)
AND   Ø Ø Ø Ø 1 1 1 1      (mask)
      ---------------
      Ø Ø Ø Ø 1 1 Ø Ø
```

the high nibble is cleared and the low nibble preserved!

OR

The four rules for OR are:

1. 0 OR 0 = 0
2. 1 OR 0 = 1
3. 0 OR 1 = 1
4. 1 OR 1 = 1

Here the OR operation will result in a 1 if *either* or *both* the bits contain a 1. A 0 will only occur if *neither* of the bits contains a 1.

Example OR the following two binary numbers:

```
      1 0 1 0
OR    0 0 1 1
      -------
      1 0 1 1
```

Here, only bit 2 is clear, the other bits are all set as each pair of tested bits contains at least one 1.

One common use of the OR operation is to ensure that a certain bit (or bits) is set—this is sometimes called 'forcing bits'. As an example, if you wish to force bit 0 and bit 7, you would need to OR the other byte with 10000001

```
      0 0 1 1 0 1 1 0       (byte being tested)
OR    1 0 0 0 0 0 0 1       (forcing byte)
      ---------------
      1 0 1 1 0 1 1 1
```

The initial bits are preserved, but bit 0 and bit 7 are 'forced' to 1.

EOR

Like AND and OR, this donkey sounding operation has four rules:

1. 0 EOR 0 = 0
2. 1 EOR 0 = 1
3. 0 EOR 1 = 1
4. 1 EOR 1 = 0

This operation is exclusive to OR, in other words, if both bits being tested are similar a 0 will result. A 1 will only be generated if the corresponding bits are unlike.

Example EOR the following two binary numbers:

```
      1 0 1 0
EOR   0 0 1 1
      -------
      1 0 0 1
```

This instruction is often used to complement, or invert, a number. Do this by EORing the other byte with 11111111.

```
      1 0 0 1 1 0 0 0       (byte being inverted)
EOR   1 1 1 1 1 1 1 1       (inverting byte)
      ---------------
      0 1 1 0 0 1 1 1
```

Compare the result with the first byte, it is completely opposite.

5 The Registers

To enable the 651Ø to carry out its various operations, it contains within it several special locations, called *registers.* Because these registers are internal to the 651Ø, they do not appear as part of the Commodore 64's memory map (see Appendix 5), and are therefore referred to by name only. Figure 5.1 shows the typical programming model of the 651Ø. For the time being we need only concern ourselves with the first four of these six registers, they are the accumulator, the X and Y registers and the Program Counter.

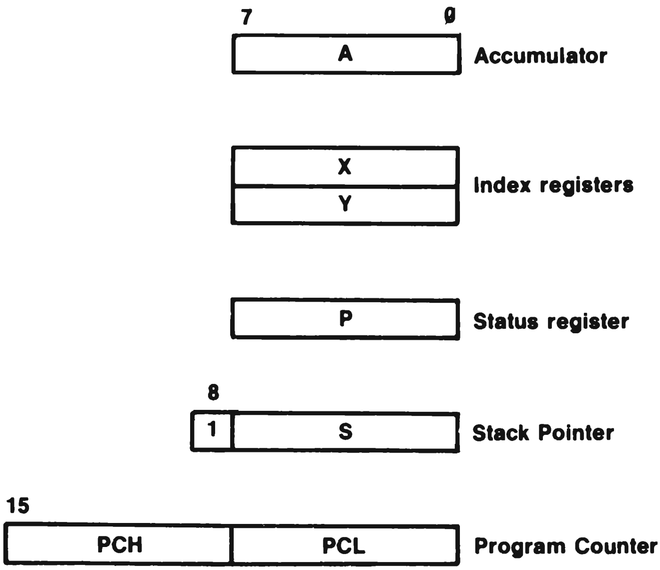


Figure 5.1 The registers—a typical programming model.

THE ACCUMULATOR

We have already mentioned the accumulator (or 'A' register) several times in the opening chapter. As you may have already gathered, the accumulator is the main register of the 651Ø, and like most of the other registers it is eight bits wide. This means that it can hold a single byte of information at any one time. Being the main register, it has the most instructions associated with it, and its principle feature is that all arithmetic and logical operations are carried out through it.

The accumulator's associated instructions are listed in Table 5.1. It is not absolutely vital to be familiar with these at present, but they are included now as an introduction.

Table 5.1

Accumulator instructions			
ADC	Add with carry	PHA	Push accumulator
AND	Logical AND	PLA	Pull accumulator
ASL	Arithmetic shift left	ROL	Rotate left
BIT	Compare memory bits	ROR	Rotate right
CMP	Compare to accumulator	SBC	Subtract with carry
EOR	Logical EOR	STA	Store the accumulator
LDA	Load the accumulator	TAX	Transfer accumulator to X register
LSR	Logical shift right	TAY	Transfer accumulator to Y register
ORA	Logical OR	TXA	Transfer X register to accumulator
		TYA	Transfer Y register to accumulator

THE INDEX REGISTERS

There are two further registers in the 651Ø which can hold single byte data. These are the *X register* and the *Y register*. They are generally termed the 'index registers', because they are very often used to provide an 'offset' or index from a specified base address. They are provided with direct increment and decrement instructions—something the accumulator lacks—so are also quite often used as counters. However, it is not possible to perform arithmetic or logical operations in either index register, but there are instructions to transfer the contents of these registers into the accumulator and vice versa.

The instructions associated with both registers are given in Table 5.2.

Table 5.2

X register instructions		Y register instructions	
CPX	Compare X register	CPY	Compare Y register
DEX	Decrement X register	DEY	Decrement Y register
INX	Increment X register	INY	Increment Y register
LDX	Load the X register	LDY	Load the Y register
STX	Store the X register	STY	Store the Y register
TAX	Transfer accumulator to X reg.	TAY	Transfer accumulator to Y reg.
TXA	Transfer X reg. to accumulator	TYA	Transfer Y reg. to accumulator
TSX	Transfer Status to X register		
TXS	Transfer X register to Status		

THE PROGRAM COUNTER

The Program Counter is the 651Ø's address book. It nearly always contains the address in memory where the next instruction to be executed sits. Unlike the other registers, it is a 16 bit register, consisting physically of two 8 bit registers. These two are generally referred to as Program Counter High (PCH) and Program Counter Low (PCL).

6 A Poke at Machine Code

Now that we have got some of the basics out of the way, why don't we write our first machine code program, after all, that's what this book is all about!

Enter Program 1—you can omit the REM statements if you like. The (hex) machine code and assembler versions of the instructions are included as REMs alongside the DATA statements (which are, of course, in decimal).

Program 1

```
10  REM * * MACHINE CODE DEMO * *
20  REM * PRINT 'A' ON SCREEN *
30  CODE = 828
40  FOR LOOP = 0 TO 5
50    READ BYTE
60    POKE CODE + LOOP, BYTE
70  NEXT LOOP
80
90  REM * * MACHINE CODE DATA * *
100 DATA 169,65       REM $A9, $41        — LDA #ASC"A"
110 DATA 32,210,255   REM $20, $D2, $FF   — JSR 65490
120 DATA 96           REM $60             — RTS
130
140 REM * * EXECUTE MACHINE CODE * *
150 SYS 828
```

The function of this short program is to print the letter 'A' on the screen. Nothing spectacular, but the program does incorporate various features that will be common to all your future machine code programs. The meaning of each line is as follows:

Line 30	Declare a variable called CODE to denote where the machine code is placed.
Line 40	Set up a data-reading loop.
Line 50	Read one *byte* of machine code data.
Line 60	POKE byte value into memory.
Line 70	Repeat loop until finished.
Line 100	Machine code data—place ASCII code for A in accumulator.
Line 110	Machine code data—print A on the screen.

Line 12Ø Machine code data—Return to BASIC.
Line 15Ø Execute the machine code

To see the effect of the program just type in RUN, hit the RETURN key and voila—the A should be sitting just above the 'READY' prompt!

CODE–THE PROGRAM COUNTER

It should be fairly obvious that the machine code we write has to be stored somewhere in memory. In all the programs in this book I have used the BASIC variable 'CODE' as a pointer to the start address of the memory where the machine code is to be placed. (CODE acts, in effect, rather like the processor's own Program Counter.) You may wish to use your own variable name—and this is perfectly acceptable. For example, you may consider that PC is a more appropriate name for the start of the code—or even MACHINECODE. It does not really matter. What does matter is that you should get into the habit of using the same variable name in *all* your programs, and thus avoid ambiguity.

The value given to CODE must be chosen with care. It would be easy enough to allocate an address which causes the machine code to overwrite another program or even the assembly program itself! In Program 1 CODE is set to 828 using the normal variable assignment statement:

CODE = 828

and the six bytes of machine code are stored there—or more correctly—in the six bytes starting at 828 (828 to 833). If you look at Figure 6.1 you will notice that this area is in the *tape input/output buffer.* The tape buffer comprises locations 828 to 1Ø19 ($Ø33C–$Ø3FB), making a total of 192 bytes available for machine code programs (provided, of course, the program does not access the cassette, thereby overwriting the machine code stored in the buffer). There are also nine free bytes below the tape buffer—from 82Ø ($Ø334) onwards. As Program 1 is only six bytes long, it could be placed there.

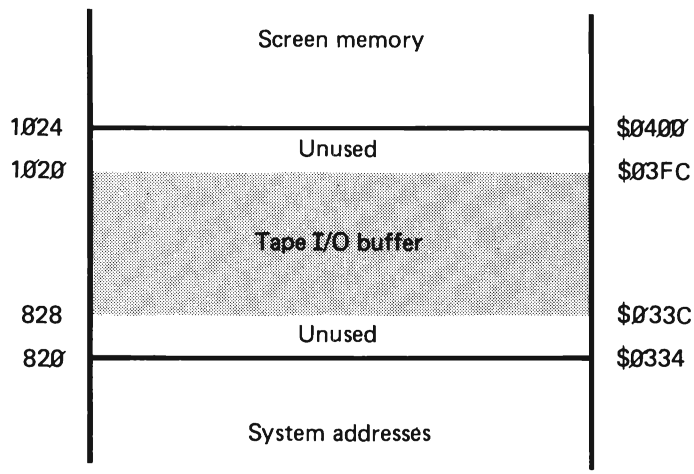


Figure 6.1 Place machine code in tape buffer.

BASIC programs are stored in the user RAM which stretches from 2Ø48 ($Ø8ØØ) to 4Ø959 ($9FFF)—a massive 38K. It is quite feasible to place your machine code programs here—but you must avoid conflict with BASIC. If your program is entirely machine code then no problems should occur, however, if it is used in conjunction with BASIC, then it must be assembled well out of harm's way. Perhaps the best area is in the middle of the user RAM from location 215Ø4 ($54ØØ) onwards, so that it is *above* all but the longest BASIC programs and *below* the downgrowing BASIC stack which is used for holding string and variable data (see Figure 6.2).

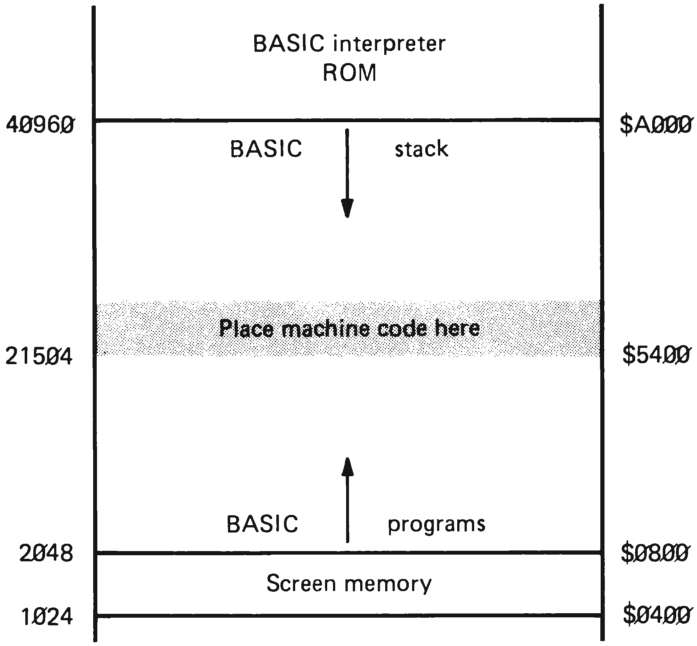


Figure 6.2 Place machine code in mid-RAM to avoid BASIC corruption.

A slightly more complex method of reserving space involves resetting the value of MEMSIZ. This is the label associated with locations 55 ($0037) and 56 ($0038), which hold the address of the highest memory location that may be used by a BASIC program. By resetting these two locations to point lower down the memory map, it is possible to create space above the BASIC user RAM and below the BASIC ROM as shown in Figure 6.3. Program 2 illustrates how this technique can be used.

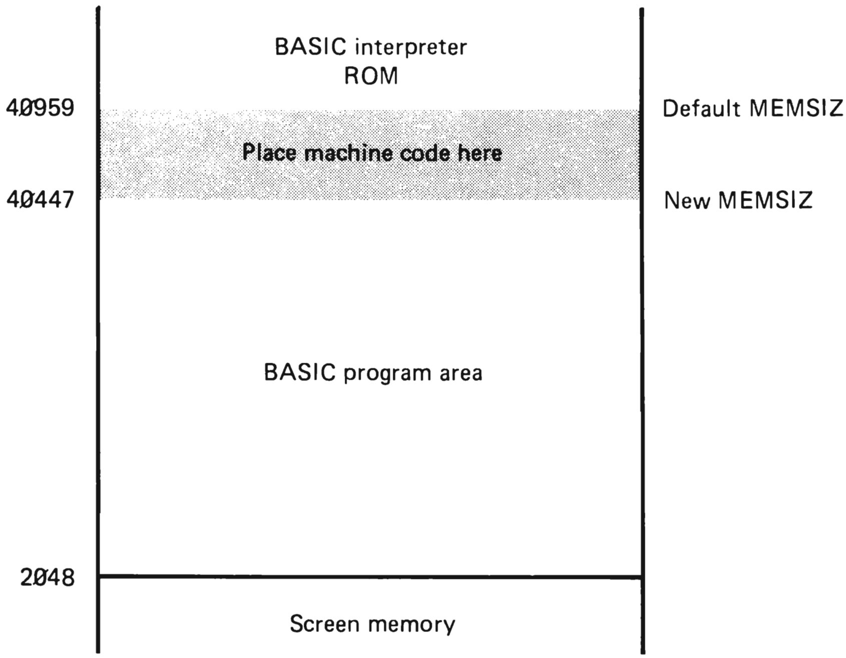


Figure 6.3 Place machine code above MEMSIZ.

Program 2

```
10  REM * * PLACE M/C ABOVE MEMSIZ * *
20  REM * * RESET MEMSIZ TO 40447 * *
30  REM * * WHICH IS $9DFF * *
40  POKE 55,255          REM low byte
50  POKE 56,157          REM high byte
60  CLR                  REM clear stack
70  CODE = 40448      :  REM set PC
80  FOR LOOP = 0 TO 5
90    READ BYTE
100   POKE CODE + LOOP, BYTE
110 NEXT LOOP
120
130 REM * * M/C DATA * *
140 DATA 169,147         REM $A9, $93          — LDA #$93
150 DATA 32,210,255      REM $20, $D2, $FF     — JSR 65490
160 DATA 96              REM $60               — RTS
170
180 SYS CODE
```

As a BASIC loader program is being used, MEMSIZ can be altered by the BASIC program itself (lines 40 and 50). If a pure machine code program is being loaded into memory, MEMSIZ can be altered in *Immediate Mode* by:

```
POKE 55, 255
POKE 56, 157
CLR
```

Note that in both instances a CLR command is also entered (line 60 in the program). This ensures that any 'old' BASIC stack values are erased, as are the pointers associated with them. These are then reset as required by the new value of MEMSIZ. Line 70 sets CODE to the value of MEMSIZ +1 *before* the DATA is READ and POKEd into the space which has been created.

You may well be wondering just what new value should be assigned to MEMSIZ. Well, this will depend on the length of the machine code you wish to place above it. The formula is simply:

40959 – Program length

(where 40959 is the default value of MEMSIZ). In general, though, it is best to add several bytes to the program length to be safe. Alternatively, just decide on an arbitrary amount of memory to keep clear and use this value. In the above example I decided to reserve 512 bytes, therefore the new value of MEMSIZ is given by:

40959 – 512 = 40447

$9FFF – $200 = 9DFF

Next comes the question of how to calculate the individual byte values to be POKEd into locations 55 and 56. If we are entering them directly in hex format, then all we need to do is to split the address into its two constitutent bytes and POKE these into memory. However, this is not possible in BASIC, so we need to calculate the decimal value of each byte as follows:

High byte   40447 / 256 = 157.996094 = 157

Low byte   40447 – (157 * 256)   = 255

The low byte (255) is POKEd into location 55 and the high byte (157) into location 56.

Oh, by the way this program produces a 'CLR' (line 140), which is the same as that obtained by pressing the SHIFT and CLR/HOME keys together. The ASCII code for 'CLR/HOME' is 147. (Line 150 will be explained later!)

Finally, there is one more area for your machine code programs which is untouched by the Commodore 64. This is memory in free RAM, from 49152 ($C000) to 53247 ($CFFF), and provides a total of 4096 bytes (see Figure 6.4). Program 3, which switches to lower case text, uses this area.

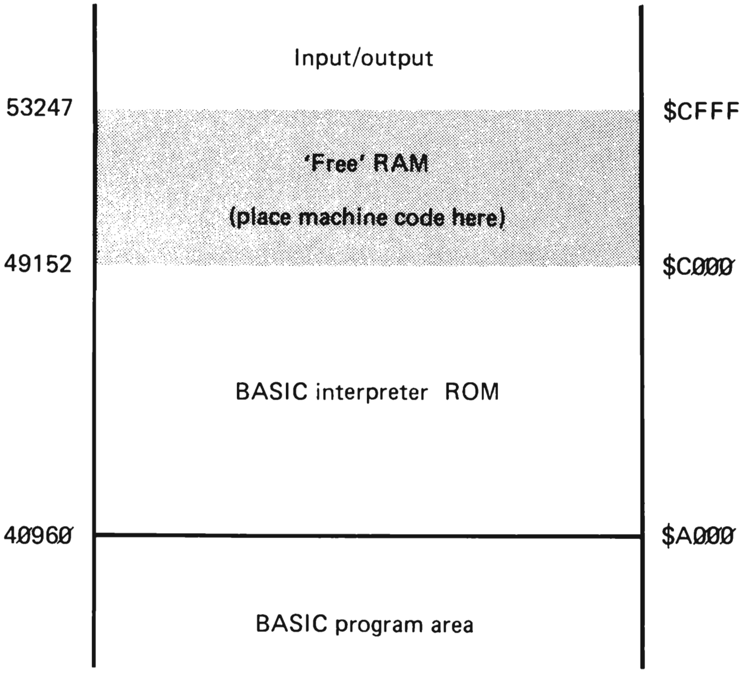


Figure 6.4   Place machine code in 'free' RAM.

Program 3

```
10 REM * * PLACE M/C IN FREE RAM * *
20 REM * * FROM 49152 ONWARDS * *
30 CODE = 49152
40 FOR LOOP = 0 TO 5
50    READ BYTE
60    POKE CODE + LOOP, BYTE
70 NEXT LOOP
80
```

```
 90  REM * * M/C DATA * *
100  DATA 169,14          REM $A9, $0E        — LDA #$0E
110  DATA 32,210,255      REM $20, $D2, $FF   — JSR 65490
120  DATA 96              REM $60             — RTS
130
140  SYS CODE
```

To get back to upper case substitute 142 (8E) for the 14 in line 100.

To summarize then, the following areas of memory can be considered 'safe' for machine code:

1. Tape I/O buffer (828–1019) (if not using cassette).
2. Unused RAM in locations:

   251–254 ($00FB–$00FE)
   679–767 ($02A7–$02FF)
   820–827 ($0334–$033B)
   1020–1023 ($03FC–$03FF)

3. In the middle of user RAM.
4. Above reset MEMSIZ.
5. In 'free' RAM between 49152 ($C000) and 53247 ($CFFF).

Most Programs in this book use the 'free' RAM area.

ENTERING MACHINE CODE

The most obvious way of entering machine code is to write a program that just contains line after line of POKEs. Program 4 shows how this method can be used to produce a machine code program that switches on the reverse character mode.

Program 4

```
10  REM * * RVS ON USING POKEs * *
20  REM * * PLACE M/C IN TAPE BUFFER * *
30  POKE 828,169       REM $A9      — LDA #'RVS ON'
40  POKE 829,18        REM $12
50  POKE 830,32        REM $20      — JSR 61898
60  POKE 831,202       REM $CA
70  POKE 832,241       REM $F1
80  POKE 833,96        REM $60      — RTS
90  SYS 828
```

To see the effect of this, add the following lines from Program 1 to write an 'A' on the screen:

```
72  POKE 833,169       REM $A9      — LDA #$41
74  POKE 834,65        REM $41
76  POKE 835,32        REM $32      — JSR 65490
78  POKE 836,210       REM $D2
```

```
80  POKE 837,255        REM $FF
82  POKE 840,96         REM $60          — RTS
```

As you may be beginning to appreciate, entering machine code in this manner is somewhat laborious, particularly when it is a very long program. In the earlier programs the machine code was placed in a series of DATA statements, which were subsequently READ from within a FOR . . . NEXT loop and then POKEd into memory using the loop counter (LOOP) as an offset from the base address defined by CODE. This ensures that each byte is placed into consecutive memory locations.

Notice also, that in each program, every machine code operation was placed in a separate DATA statement, and was accompanied by a REM statement giving the same information in both the hex and mnemonic formats, for example:

```
100  DATA 169,65        REM $A9, $41     — LDA #ASC ("A")
```

The REM items are included for flexibility. Each of the programs can be entered and RUN exactly as it stands, thus allowing you to get programming in machine code straightaway; however, if at some time in the future you invest in an *Assembler* program then you'll need to know the mnemonic versions. (The hex values are included for a reason that will soon become apparent!)

It is a good idea to get into the habit of including this type of REM statement into your own programs simply because it adds to the program's readability. Imagine being presented with a program that includes a single DATA statement:

```
100  DATA 169, 14, 32, 208, 241, 169, 146, 32, 202, 241, 96
```

Its not particularly clear what's being performed, and if you need to debug it, well . . . !

One final point regarding the loop count. This should be set to the total number of data bytes minus one. Remember that the loop counter itself must always start at '0' to ensure that the very first byte is placed at the address specified by CODE—CODE + LOOP = 828 + 0 = 828 (if CODE = 828).

THE HEX LOADER PROGRAM

An easier method of entering machine code is to use a *monitor* or *hex loader program.* This is a program which allows machine code to be entered as a series of hex numbers. Program 5 is a simple example.

Program 5

```
10  REM * * COMMODORE 64 HEX LOADER * *
20  PRINT CHR$(147)
30  PRINT SPC(8)
40  PRINT "COMMODORE 64 MONITOR"
50  PRINT : PRINT
60  INPUT "ASSEMBLY ADDRESS"; A$
70  ADDR = VAL(A$)
80  REM * * MAIN PROGRAM LOOP * *
90  PRINT ADDR; " :$";
100 REM * * GET HIGH NIBBLE OF BYTE * *
110 GOSUB 2000
120 HIGH = NUM
130 PRINT Z$;
```

```
140  REM * * GET LOW NIBBLE OF BYTE * *
150  GOSUB 2000
160  LOW = NUM
170  PRINT Z$
180  REM * * CALCULATE BYTE AND UPDATE * *
190  BYTE = HIGH * 16 + LOW
200  POKE ADDR, BYTE
210  ADDR = ADDR + 1
220  GOTO 80
300
500  REM * * SUBROUTINE * *
2000 GET Z$
2010 IF Z$ = "S" THEN PRINT "STOP" : END
2020 IF Z$ > "F" THEN GOTO 2000
2030 IF Z$ = "A" THEN NUM = 10 : RETURN
2040 IF Z$ = "B" THEN NUM = 11 : RETURN
2050 IF Z$ = "C" THEN NUM = 12 : RETURN
2060 IF Z$ = "D" THEN NUM = 13 : RETURN
2070 IF Z$ = "E" THEN NUM = 14 : RETURN
2080 IF Z$ = "F" THEN NUM = 15 : RETURN
2090 IF Z$ = " " THEN GOTO 2000
2100 NUM = VAL(Z$) : RETURN
```

The meaning of each line is as follows:

Line 20	Clear screen and HOME cursor.
Line 40	Print heading.
Line 50	Print two linefeeds.
Line 60	Get start address for machine code.
Line 70	Convert string into numeric value.
Line 90	Print address and '$'.
Line 110	Get high nibble of hex byte.
Line 120	Save its value in HIGH.
Line 130	Print high nibble.
Line 150	Get low nibble of hex byte.
Line 160	Save its value in LOW.
Line 170	Print low nibble.
Line 180	Calculate byte value.
Line 200	POKE it into memory.
Line 210	Increment memory counter.
Line 220	Repeat.
Line 2000	Get key.
Line 2010	If it's an S then end program.
Line 2020	If it's greater than F go back to 2000 and ignore it.
Line 2030–2080	If it's in the range A to F declare its value and return.
Line 2090	If no key pressed go back to 2000.
Line 2100	Calculate value and return.

Enter and RUN the program. After it displays the heading you are asked to input an 'Assembly address'. This is simply the address that you would normally assign to CODE, and should be entered as a decimal value. On hitting RETURN the first program address is displayed followed by a dollar sign, $. All you now have to do is to type in the hex digits. After you type the second digit, the byte value is calculated and then POKEd into memory. The next address is then displayed. The program checks for (and ignores) non-hex characters. To leave the monitor at any time type 'S' (for Stop!). Figure 6.5 shows the result of a typical monitor run. Once entered the machine code can be tested using a SYS call to the address of the first byte of machine code.

```
COMMODORE 64 MONITOR

Assembly address ? 828

828 : $A9
829 : $41
830 : $20
831 : $D2
832 : $FF
833 : $60
834 : $ STOP

READY.
```

Figure 6.5 A typical monitor run.

CALLING MACHINE CODE

To execute a machine code program the BASIC statement 'SYS' is used. To tell the BASIC interpreter just where the machine code is located, the SYS statement must be followed by a label or an address. So, to execute the machine code generated by the assembly language program type in either:

SYS CODE

which is the label name which marks the start of the assembly language program, or:

SYS 49152

which is the start address of the machine code itself.

GETTING IT TAPED

It is a very good idea, as a matter of routine, to get into the habit of saving your machine code programs on tape *before* you actually RUN them. This may seem a bit back to front because you normally would not do this in BASIC until you had RUN, tested and debugged the program. The trouble with running a machine code program for the first time, though, is that if it does contain any bugs it will almost certainly cause the Commodore 64 to 'hang-up', and the only way out of this is to switch the micro off and then back on, and start all over again. If your machine code does fail in this way, and you've saved it on tape, all you have to do is to reLOAD it and swat the bug out!

Once the program is fully debugged it is possible to save just the machine code if so required. We shall look at how to do this in Chapter 20.

THE KERNAL

Supplied pre-packed within every Commodore 64 micro is a set of machine code routines which are available for use from within machine code programs. These routines belong to a part of the Operating System called the Kernal. There are 39 routines in total, but for the present we need only concern ourselves with the more commonly used ones which are summarized in Table 6.1.

Table 6.1

Routine	Address	Operation
CHRIN	65487 ($FFCF)	Input character from channel
CHROUT	65490 ($FFD2)	Output character to channel
GETIN	65508 ($FFE4)	Get character from keyboard queue
SCNKEY	65439 ($FF9F)	Scan keyboard
STOP	65505 ($FFE1)	Scan STOP key

We have already used the CHROUT routine several times to write the character in the accumulator to the screen. The instruction takes the form JSR 65490; the mnemonic 'JSR' simply tells the 6510 microprocessor to jump to the address given, and then come back here when finished. This is known as a 'subroutine'—which we shall look at in detail in Chapter 14.

7 Status Symbols

THE STATUS REGISTER

The Status register is unlike the various 'other' registers of the 6510. When using it, we are not really concerned with the actual hex value it contains, but more with the condition or state of its individual bits. These individual bits are used to denote or *flag* certain conditions as and when they occur during the course of a program. Of the register's eight bits, only seven are in use—the remaining bit (bit 5) is permanently set. (In other words it always contains a 1.)

Figure 7.1 shows the position of the various flags, each of which is now described in detail.

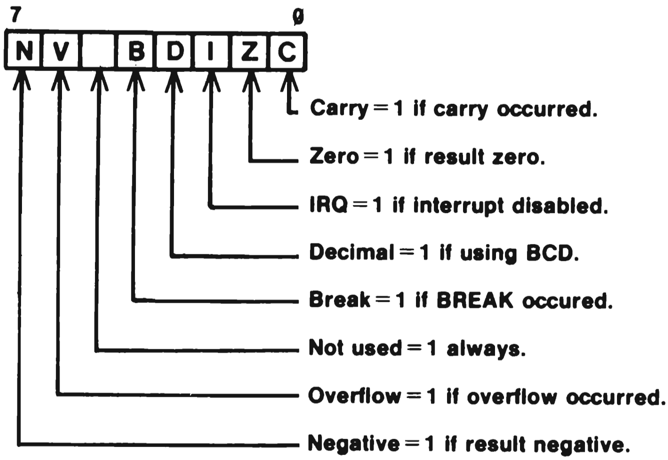


Figure 7.1 Status register flags.

Bit 7: The Negative flag (N)

In signed binary, the Negative flag is used to determine the sign of a number. If the flag is set (N = 1) the result is negative. If the flag is clear (N = 0) the result is positive.

However a whole host of other instructions condition this particular flag, including all the arithmetic and logical instructions. In general, the most significant bit of the result of an operation is copied directly into the N flag.

Consider the following two operations:

```
LDA #$80        \ load accumulator with $80
```

This will set the Negative flag (N = 1) because $80 = 10000000 in binary. Alternatively:

```
LDA #$7F        \ load accumulator with $7F
```

will clear the Negative flag (N = Ø) because $7F = Ø1111111 in binary. There are two instructions which act on the state of the N flag—these are:

BMI   Branch on minus (N = 1)

BPL   Branch on plus (N = Ø)

More on these later.

Bit 6: The Overflow flag (V)

This flag is probably the least used of all the Status register flags. It is used to indicate if a carry occurred from bit 6 during an addition, or if a borrow occurred to bit 6 in a subtraction. If either of these events took place the flag is set (V = 1).

Look at the following two examples:
First, $Ø9 + $Ø7:

```
($Ø9)      Ø Ø Ø Ø 1 Ø Ø 1
($Ø7)     +Ø Ø Ø Ø Ø 1 1 1
           ---------------
($1Ø)      Ø Ø Ø 1 Ø Ø Ø Ø
           ↑
           └─────No overflow from bit 6 therefore V = Ø.
```

Second, $7F + $Ø1:

```
($7F)      Ø 1 1 1 1 1 1 1
($Ø1)     +Ø Ø Ø Ø Ø Ø Ø 1
           ---------------
($8Ø)      1 Ø Ø Ø Ø Ø Ø Ø
           ↑
           └─────Overflow has occurred from bit 6 therefore V = 1.
```

If we were using signed binary this addition would give a result of −128, which is of course incorrect. However this fact is flagged and so the result can be corrected as required.

Bit 5

This bit is not used and is permanently set.

Bit 4: The Break flag (B)

This flag is set whenever a BREAK occurs, otherwise it will remain clear. This may seem a bit odd at first, because surely we will know when a BREAK occurs. However, it is possible to generate a BREAK externally by something called an *Interrupt*, and this flag is used to help distinguish between these 'BREAKs'.

Bit 3: The Decimal flag (D)

This flag tells the processor just what type of arithmetic is being used. If it is cleared (by CLD), as is usual, then normal hexadecimal operation occurs. If set (by SED) all values will be interpreted as Binary Coded Decimal.

Bit 2: The Interrupt flag (I)

We mentioned interrupts above in the description of the Break flag, and they will be looked at in more detail in Chapter 22. Suffice to say now, that the flag is set (I = 1) when the IRQ interrupt is disabled, and is clear (I = Ø) when IRQ interrupts are permitted.

Bit 1: The Zero flag (Z)

As its name implies, the flag is used to show whether or not the result of an operation is zero. If the result is zero the flag is set (Z = 1), otherwise it is cleared (Z = 0). It is true to say that the Zero flag is conditioned by the same instructions as the Negative flag. Executing:

```
LDA #0          \ load accumulator with zero
```

will set the Zero flag (Z = 1) but:

```
LDX #$FA        \ load X register with $FA
```

will clear the Zero flag (Z = 0).

Bit 0: The Carry flag (C)

We have already seen that adding two bytes together can result in carries occurring from one bit to another. What happens if the carry is generated by the most significant bits of an addition?

For example, when adding $FF + $80:

```
($FF)        1 1 1 1 1 1 1 1
($80)      + 1 0 0 0 0 0 0 0
             ---------------
($7F)     (1)0 1 1 1 1 1 1 1
           ^
           └Carry over from bits 7
```

the result is just too large for eight bits, an extra ninth bit is required. The Carry flag acts as this ninth bit.

If the Carry flag is clear at the start of an addition (C = 0) and set on completion (C = 1) the result is greater than 255. It follows that if the flag is set (C = 1) before a subtraction and clear on completion (C = 0), the value being subtracted was larger than the original value. Two instructions are available for direct use on the Carry flag:

CLC	Clear Carry flag (C = 0)
SEC	Set Carry flag (C = 1)

Two instructions are also provided to act on the condition of the Carry flag.

BCC	Branch on Carry clear (C = 0)
BCS	Branch on Carry set (C = 1)

8 Addressing Modes I

The 651Ø has quite a small instruction set when compared with some of its fellow microprocessors—in fact it has a basic clique of just 56 instructions. However, many of these can be used in a variety of ways, which effectively increases the range of operations to 152. The way in which these instructions are interpreted is determined by the *addressing mode* used. The following examples are in hex format.

Addressing mode	Mnemonic example	Opcode	Operand(s)
Immediate	LDA #255	A9	FF
Zero page	LDA $FB	A5	FB
Zero page indexed	LDA $FB, X	B5	FB
Absolute	LDA $CDØØ	AD	ØØ CD
Indirect pre-indexed	LDA ($FB, X)	A1	FB
Indirect post-indexed	LDA ($FB), Y	B1	FB
Absolute indexed	LDA $CDØØ, X	BD	ØØ CD

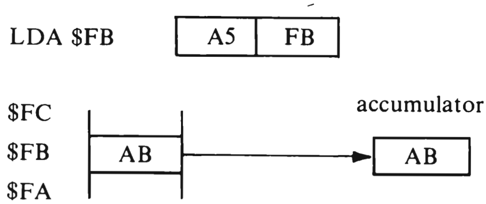
All seven of these instructions load the accumulator—but in each case the data loaded is obtained from a different source as defined by the opcode. This, as you may have noticed, is different in each case.

For the time being we shall only look at the first two of these addressing modes, immediate and zero page, both of which we have used several times already.

ZERO PAGE ADDRESSING

Zero page addressing is used to specify an address in the first 256 bytes of RAM where data which has to be loaded into a specified register may be located. Because the high byte of the address is always $ØØ it is omitted, and therefore the instruction and address require just two bytes of memory.

Operation: DATA $A5, $FB



In the example, LDA $FB, the contents of location $FB (in this case $AB) are loaded into the accumulator.

The use of zero page needs some care as this area is used by the BASIC interpreter as a scratchpad for storing addresses and performing calculations. However, Commodore have kept a few bytes clear for us to use as we please. These bytes are located between 251 ($ØØFB) and 254 ($FE) inclusive, and are of great importance as we shall see later on. The instructions associated with zero page addressing are shown in Table 8.1.

Table 8.1

Zero page addressing instructions

ADC	Add with carry	LDX	Load X register
AND	Logical AND	LDY	Load Y register
ASL	Arithmetic shift left	LSR	Logical shift right
BIT	Bit test	ORA	Logical OR
CMP	Compare accumulator	ROL	Rotate left
CPX	Compare X register	ROR	Rotate right
CPY	Compare Y register	SBC	Subtract with carry
DEC	Decrement memory	STA	Store accumulator
EOR	Logical EOR	STX	Store X register
INC	Increment memory	STY	Store Y register
LDA	Load accumulator		

IMMEDIATE ADDRESSING

This form of addressing is used to load the accumulator or the index registers with a specific value which is known at the time of writing the program. The 651Ø knows from the opcode that the byte following is in actual fact data and not an address. However, to remind *us* of the fact, and to assist us when we are writing the initial assembler, we can precede the data byte with a hash sign, '#' (this shares the '3' key on the 64's keyboard). Only single byte values can be specified because the register size is limited to just eight bits.

If we wish our machine code program to load the accumulator with 255, we can include the following two-byte sequence in our program:

```
DATA 169, 255        : REM $A9, $FF       — LDA #$FF
```

where 169 ($A9) is the 'load the accumulator immediate' code.

Similarly, the X and Y registers can be loaded immediately with:

```
DATA 162,65            REM $A2, $41       — LDX #ASC("A")
DATA 16Ø,7             REM $AØ, $Ø7       — LDY #$Ø7
```

Where 162($A2) and 16Ø($AØ) are the immediate codes for loading the X and Y registers, and 65($41) is the ASCII code for the letter A.

Operation:

LDA #$FF	A9	FF

Accumulator	FF

Program 6 uses both zero page and immediate addressing to place an exclamation mark on the screen.

Program 6

```
 10 REM * * ZERO PAGE AND IMMEDIATE ADDRESSING * *
 20 CODE = 49152
 30 FOR LOOP = 0 TO 9
 40   READ BYTE
 50   POKE CODE + LOOP, BYTE
 60 NEXT LOOP
 70
 80 REM * * M/C DATA * *
 90 DATA 162,33           REM $A2, $21       — LDX #ASC"!"
100 DATA 134,251          REM $86, $FB       — STX $FB
110 DATA 165,251          REM $A5, $FB       — LDA $FB
120 DATA 32,210,255       REM $20, $D2, $FF  — JSR $FFD2
130 DATA 96               REM $60            — RTS
140
150 SYS CODE
```

The meaning of each line is as follows:

Line 20	Assemble in 'free' RAM at $C000.
Lines 30–60	READ and POKE machine code.
Line 90	Load X register with ASCII code for '!'.
Line 100	Store X register contents in location $FB.
Line 110	Load accumulator with contents of location $FB.
Line 120	Jump to subroutine to print accumulator's contents.
Line 130	Return to BASIC.
Line 150	Call machine code.

9 Bits and Bytes

LOAD, STORE AND TRANSFER

To enable memory and register contents to be altered and manipulated, three sets of instructions are provided.

Load instructions

The process of placing memory contents into a register is known as *loading*, some examples of which we have already seen. To recap however, these are the three load instructions:

LDA	Load accumulator
LDX	Load X register
LDY	Load Y register

All of these instructions may be used with immediate addressing, but when dealing with memory locations, it is more correct to say that the contents of the specified address are *copied* into the particular register, as the source location is not altered in any way.

For example, with LDA $70, the contents of location $70 (in this case FA) are copied into the accumulator, location $70 is not altered:

The Negative and Zero flags of the Status register are conditioned by the load operation.

Store instructions

The reverse process of placing a register's contents into a memory location, is known as *storing*. There are three store instructions:

STA	Store accumulator
STX	Store X register
STY	Store Y register

The register value is unaltered and no flags are conditioned.

Example:

```
LDA #0
STA $1500
```

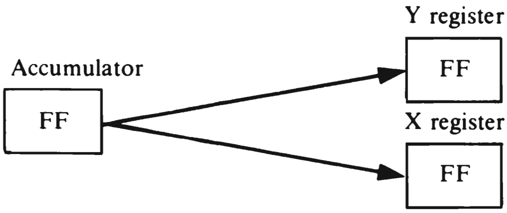
Transfer instructions

Instructions are provided to allow the contents of one register to be copied into another—this is known as *transferring*. The Negative and Zero flags are conditioned according to the data being transferred. There are four instructions controlling transfers between the index registers and the accumulator.

TXA	Transfer X register to accumulator
TAX	Transfer accumulator to X register
TYA	Transfer Y register to accumulator
TAY	Transfer accumulator to Y register

Example:

```
LDA #$FF
TAY
TAX
```



Unfortunately, you cannot transfer directly between the X and Y registers, you have to use the accumulator as an intermediate store.

```
YTOX  TYA        \ Y into accumulator
      TAX        \ accumulator into X
```

Similarly:

```
XTOY  TXA        \ X into accumulator
      TAY        \ accumulator into Y
```

This form of single byte operation is known as *implied addressing* because the information is contained within the instruction itself.

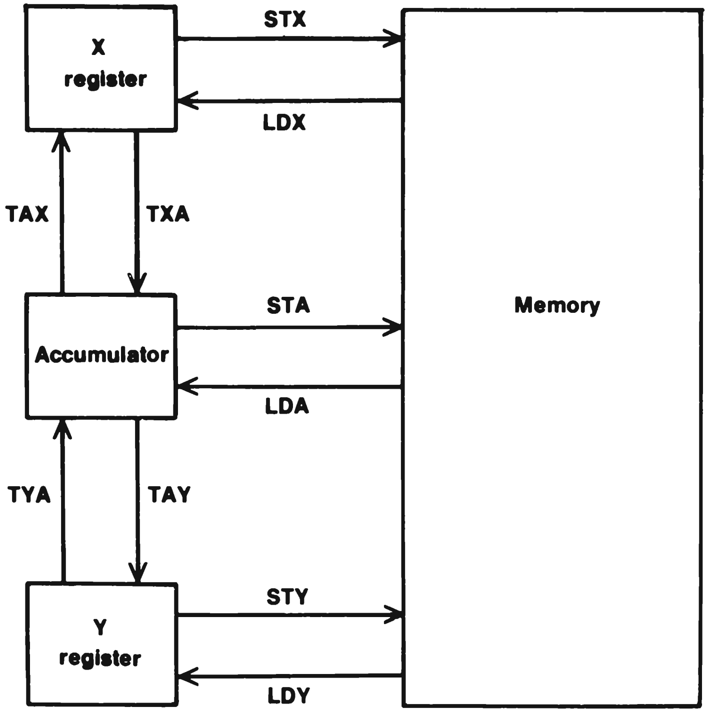


Figure 9.1 Load, store and transfer instruction flow.

PAGING MEMORY

We have seen that the Program Counter consists of two eight bit registers, giving a total of 16 bits. If all these bits are set, 11111111 11111111, the value obtained is 65536 or $FFFF. Therefore the maximum addressing range of the 651Ø is $ØØØØ through to $FFFF. This range of addresses is implemented as a series of *pages* and the page number is given by the contents of PCH. It follows that PCL holds the address of the location on that particular page.

As Figure 9.2 illustrates, each page of memory can be likened to a page of a book. This book, called '64's Memory', has 256 pages labelled in hex format from $ØØ to $FF. Each individual page is ruled into 256 lines which in turn are labelled (from top to bottom) $ØØ to $FF.

Thus the address $FFFF refers to line $FF on page $FF, the very last location in the Commodore's memory map! Unlike conventional books, '64's Memory' begins with page $ØØ which is known more affectionately as *zero page*. Owing to the 651Ø's design zero page is very important, as we shall see when we take a further look at addressing modes in the next chapter.

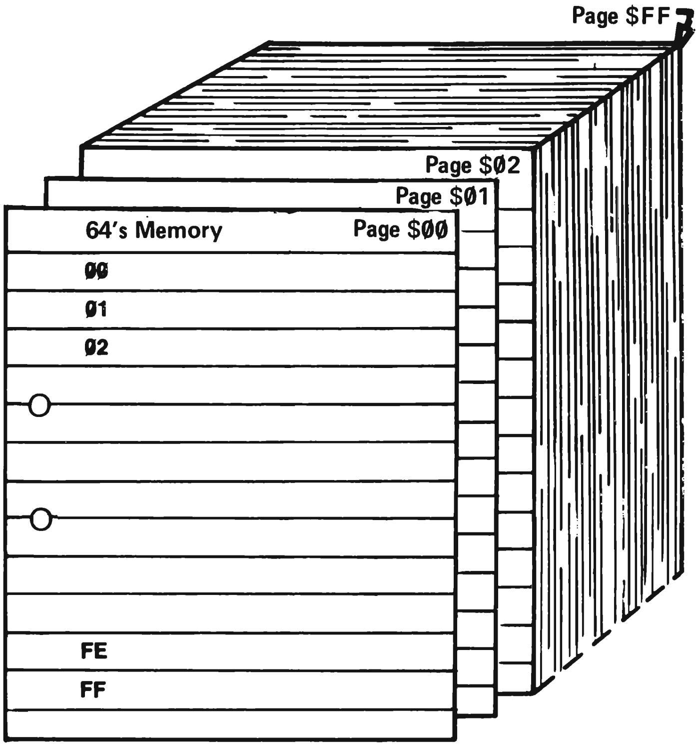


Figure 9.2 Pages of '64's Memory'.

Although we have referred to the 64's memory map as a series of pages, it is more frequently talked of in terms of 'K'. The term 'K' is short for kilo, but unlike its metric counterpart, one kilo of memory, or a kilobyte, consists of 1Ø24 bytes and not 1ØØØ bytes. This slightly higher value is chosen because it is divisible by 256 and corresponds to exactly four pages of memory (4 × 256 = 1Ø24). The total memory map therefore encompasses 64K because 65536/1Ø24 = 64!

10 Arithmetic in Assembler

We can now put some of the basic principles we have encountered in the opening chapters to some more serious use—the addition and subtraction of numbers. These two procedures are fundamental to assembly language and will generally find their way into most programs.

ADDITION

Two instructions facilitate addition, they are:

CLC	Clear Carry flag
ADC	Add with carry

The first of these instructions, CLC, simply clears the Carry flag (C = 0). This will generally be performed at the very onset of addition, because the actual addition instruction, ADC, produces the sum of the accumulator, the memory byte referenced and the Carry flag. The reason for doing this will become clearer after we have looked at some simple addition programs. Enter Program 7.

Program 7

```
10  REM * * SIMPLE ADD * *
20  CODE = 49152
30  FOR LOOP = 0 TO 7
40     READ BYTE
50     POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 24              REM $18          -- CLC
100 DATA 169,7           REM $A9, $07     — LDA #$07
110 DATA 105,3         : REM $69, $03     — ADC #$03
120 DATA 133,251       : REM $85, $FB     — STA $FB
130 DATA 96            : REM $60          — RTS
140
```

```
150  SYS CODE
160  PRINT "ANSWER IS   : ";
170  PRINT PEEK(251)
```

As you can see, this program loads 7 into the accumulator using immediate addressing. Immediate addressing is used again in line 110 to add 3 to the accumulator value. The result, which is in the accumulator, is then stored at location 251. Line 150 executes the assembled machine code, and the result (if you're quick with your fingers you'll know its 10!) is printed out. RUN the program to see its effect then try substituting your own values in lines 100 and 110.

Re-type line 90 thus:

```
90  DATA 56            REM $38          — SEC
```

As you probably realize, the Carry flag will now be set (C = 1) when the program is next executed. Reset lines 100 and 110 (if you have altered them), and RUN the program again. The result is now 11. The reason being that the Carry flag's value is taken into consideration during ADC (add with carry) and this time its value is 1.

	Accumulator	+	memory	+	carry	=	result
CLC	7	+	3	+	0	=	10
SEC	7	+	3	+	1	=	11

Again you might like to try your own immediate values—you'll find the result is always one greater than expected.

This program is quite wasteful both in terms of memory used and time taken for execution. If we know the values to be added together beforehand, then it is more efficient to add them together first. The machine code part of the program can then be incorporated into just two lines:

```
LDA #10          \ place 10 (7 + 3) into accumulator
STA $FB          \ store accumulator
```

Program 8 is a general purpose single byte addition program.

Program 8

```
10   REM * * SINGLE BYTE ADD * *
20   CODE = 49152
30   FOR LOOP = 0 TO 7
40      READ BYTE
50      POKE CODE + LOOP, BYTE
60   NEXT LOOP
70
80   REM * * M/C DATA * *
90   DATA 24          : REM $18          — CLC
100  DATA 165,251     : REM $A5, $FB     — LDA $FB
110  DATA 101,252     : REM $65, $FC     — ADC $FC
120  DATA 133,253     : REM $85, $FD     — STA $FD
130  DATA 96          : REM $60          — RTS
```

```
140
150  PRINT CHR$(147)
160  PRINT "SINGLE BYTE ADD DEMO"
170  PRINT : PRINT
180  INPUT "FIRST NUMBER";A
190  INPUT "SECOND NUMBER";B
200  POKE 251, A : POKE 252, B
210  SYS CODE
220  PRINT "ANSWER IS :";
230  PRINT PEEK(253)
```

RUN the program a few times entering low numerical values in response to the program's prompts.

Now enter 128 and 128 as your inputs. The result is 0, why? The reason is that the answer, 256, is too big to be held in a single byte:

```
   128         $80         10000000
 + 128       + $80       + 10000000
   ---         ----        --------
   256        $100      (1)00000000
```

and as can be seen, a carry has been produced by the bit overflow from adding the two most significant bits. As the Carry flag was initially cleared before the addition, it will now be set, signalling the fact that the result is too large for a single byte.

This principle is used when summing multibyte numbers, and is illustrated by Program 9, which adds two double byte numbers

Program 9

```
10   REM * * DOUBLE BYTE ADD * *
20   CODE = 49152
30   FOR LOOP = 0 TO 13
40      READ BYTE
50      POKE CODE + LOOP, BYTE
60   NEXT LOOP
70
80   REM * * M/C DATA * *
90   DATA 24              REM $18          — CLC
100  DATA 165,251         REM $A5, $FB     — LDA $FB
110  DATA 101,253         REM $65, $FD     — ADC $FD
120  DATA 133,251         REM $85, $FB     — STA $FB
130  DATA 165,252         REM $A5, $FC     — LDA $FC
140  DATA 101,254         REM $65, $FE     — ADC $FE
150  DATA 133,252       : REM $85, $FC     — STA $FC
160  DATA 96              REM $60          — RTS
170
180  PRINT CHR$(147)
```

```
190  PRINT "DOUBLE BYTE ADD DEMO"
200  PRINT : PRINT
210  INPUT "FIRST NUMBER";A
220  REM CALCULATE HIGH AND LOW BYTE
230  AH = INT(A/256)
240  AL = A - (AH * 256)
250  INPUT "SECOND NUMBER";B
260  REM CALCULATE HIGH AND LOW BYTE
270  BH = INT(B/256)
280  BL = B - (BH * 256)
290  POKE 251, AL : POKE 252, AH
300  POKE 253, BL : POKE 254, BH
310  SYS CODE
320  LOW = PEEK(251) : HIGH = PEEK(252)
330  RESULT = HIGH * 256 + LOW
340  PRINT "ANSWER IS :";
350  PRINT RESULT
```

The meaning of each line is as follows:

Line 20	Assemble code in 'free' RAM from $C000.
Lines 30–60	READ and POKE machine code data.
Line 90	Clear Carry flag.
Line 100	Get low byte of first number, AL.
Line 110	Add it to low byte of second number, BL.
Line 120	Store low byte of result.
Line 130	Get high byte of first number, AH.
Line 140	Add it to high byte of second number, BH.
Line 150	Store high byte of result.
Line 160	Return to BASIC.
Lines 180–190	Clear screen and print title.
Line 210	Input first number.
Line 230	Calculate high byte value of A.
Line 240	Calculate low byte value of A.
Line 250	Input second number.
Line 270	Calculate high byte value of B.
Line 280	Calculate low byte value of B.
Lines 290–300	POKE high and low byte values of A, B into memory.
Line 310	Execute machine code.
Line 320	Get low and high bytes of the result.
Line 330	Calculate result.
Lines 340–350	Print result.

This routine will produce correct results for any two numbers whose sum is not greater than 65536 ($FFFF) which is the highest numerical value that can be held in two bytes of memory.

Note that the Carry flag is cleared at the onset of the machine code itself. If any carry should occur when adding the two low bytes together, it will be transferred over to the addition of the two high bytes.

SUBTRACTION

The two associated instructions are:

SEC	Set Carry flag
SBC	Subtract, borrowing carry

The operation of subtracting one number from another (or finding their difference) is the reverse of that used in the preceding addition examples. Firstly the Carry flag is set (C = 1) with SEC, and then the specified value is subtracted from the accumulator using SBC. The result of the subtraction is returned in the accumulator.

The following program performs a single byte subtraction:

Program 10

```
10Ø REM * * SIMPLE SUBTRACTION * *
2Ø  CODE = 49152
3Ø  FOR LOOP = Ø TO 7
4Ø     READ BYTE
5Ø     POKE CODE + LOOP, BYTE
6Ø  NEXT LOOP
7Ø
8Ø  REM * * M/C DATA * *
9Ø  DATA 56          : REM $38         — SEC
1ØØ DATA 165,251       REM $A5, $FB    — LDA $FB
11Ø DATA 229,252       REM $E5, $FC    — SBC $FC
12Ø DATA 133,253       REM $85, $FD    — STA $FD
13Ø DATA 96            REM $6Ø         — RTS
14Ø
15Ø PRINT CHR$(147)
16Ø INPUT "HIGHEST NUMBER";A
17Ø INPUT "LOWEST NUMBER";B
18Ø POKE 251, A : POKE 252, B
19Ø SYS CODE
2ØØ PRINT "ANSWER IS ";
21Ø PRINT PEEK(253)
```

The meaning of each line is as follows:

Lines 2Ø–6Ø	Assemble machine code.
Line 9Ø	Set Carry flag.
Line 1ØØ	Load high number into the accumulator.
Line 11Ø	Subtract contents of $FC from it.
Line 12Ø	Save result in $FD.
Line 13Ø	Back to BASIC.
Lines 16Ø–17Ø	Get two values.
Line 18Ø	POKE them into zero page.
Line 19Ø	Call machine code.
Lines 2ØØ–21Ø	Print the answer.

RUN the program and input your own values to see the results.

You may well be wondering why the Carry flag is set before a subtraction rather than cleared. Referring back to Chapter 3, you will recall that the subtraction there was performed by adding the two's complement value. This is found by first inverting all the bits to obtain the one's complement, and then adding 1. The 6510 obtained the 1 to be added to the one's complement form, from the Carry flag. Thus we can say:

1. If the Carry flag is set after SBC, the result is positive or zero.
2. If the Carry flag is clear after SBC, the result is negative and a borrow has occurred.

Try changing line 90 to DATA 24 : REM $18—CLC and re-RUN the program. Now your results are one less than expected—the reason being that the two's complement was never obtained by the 6510, because only a '0' was available in the Carry flag to be added to the one's complement value.

To subtract double byte numbers the Carry flag is set at the entry to the routine, and the relative bytes are subtracted and stored. The resulting program looks something like this:

Program 11

```
 10 REM * * DOUBLE BYTE SUBTRACTION * *
 20 CODE = 49152
 30 FOR LOOP = 0 TO 13
 40    READ BYTE
 50    POKE CODE + LOOP, BYTE
 60 NEXT LOOP
 70
 80 REM * * M/C DATA * *
 90 DATA 56            REM $38         — SEC
100 DATA 165,251       REM $A5, $FB    — LDA $FB
110 DATA 229,253       REM $E5, $FD    — SBC $FD
120 DATA 133,251       REM $85, $FB    — STA $FB
130 DATA 165,252       REM $A5, $FC    — LDA $FC
140 DATA 229,254       REM $E5, $FE    — SBC $FE
150 DATA 133,252       REM $85, $FC    — STA $FC
160 DATA 96            REM $60         — RTS
170
180 PRINT CHR$(147)
190 INPUT "HIGHEST NUMBER";A
200 INPUT "LOWEST NUMBER";B
210 REM CALCULATE HIGH AND LOW BYTES
220 AH = INT(A / 256)
230 AL = A - (AH * 256)
240 BH = INT(B / 256)
250 BL = B - (BH * 256)
260 POKE 251, AL : POKE 252, AH
270 POKE 253, BL : POKE 254, BH
```

```
280  SYS CODE
290  LOW = PEEK(251) : HIGH = PEEK(252)
300  RESULT = HIGH * 256 + LOW
310  PRINT "ANSWER IS ";
320  PRINT RESULT
```

The meaning of each line is as follows:

Lines 20–60	Assemble machine code.
Line 90	Set the Carry flag.
Line 100	Load low byte of high number into accumulator.
Line 110	Subtract low byte of low number from it.
Line 120	Save low byte of result in $FB.
Line 130	Load high byte of high number into accumulator.
Line 140	Subtract high byte of low number from it.
Line 150	Save high byte of result in $FC.
Line 160	Back to BASIC.
Lines 180–200	Get two numbers.
Lines 220–270	Calculate and store high and low bytes.
Line 280	Call machine code.
Lines 290–300	Calculate final result.
Lines 310–320	Print the answer.

NEGATION

The SBC instruction can be used to convert a number into its two's complement form. This is done by subtracting the number to be converted, from zero. The following program asks for a decimal value (less than 255) and prints its two's complement value in hex:

Program 12

```
10   REM * * TWO'S COMPLEMENT CONVERTER * *
20   CODE = 49152
30   FOR LOOP = 0 TO 7
40      READ BYTE
50      POKE CODE + LOOP, BYTE
60   NEXT LOOP
70
80   REM * * M/C DATA * *
90   DATA 56              REM $38          — SEC
100  DATA 169,0           REM $A9, $00     — LDA #0
110  DATA 229,251         REM $E5, $FB     — SBC $FB
120  DATA 133,252      :  REM $85, $FC     — STA $FC
130  DATA 96              REM $60          — RTS
140
150  PRINT CHR$(147)
160  INPUT "NUMBER TO BE CONVERTED";A
170  IF A > 255 THEN PRINT "ERROR" : GOTO 160
```

```
180  POKE 251, A
190  SYS CODE
200  PRINT "THE TWO'S COMPLEMENT VALUE IS :";
210  PRINT PEEK(252)
```

The meaning of each line is as follows:

Lines 20–60	Assemble machine code.
Line 90	Set the Carry flag.
Line 100	Load accumulator with 0.
Line 110	Subtract the contents of $FB from it.
Line 120	Save result in $FC.
Line 130	Back to BASIC.
Lines 150–160	Get number.
Line 170	Make sure it's less than 256.
Line 180	POKE number into $FB.
Line 190	Execute machine code.
Line 200–210	Print result.

USING BCD

We can now investigate the use of BCD in assembly language programs. You will remember from Chapter 3 that 6 must be added to (or subtracted from) the result of an addition (or subtraction) whenever a transition occurs from 9 to 10 or vice versa. This causes the six unused binary combinations, normally used to represent A to F in hex, to be jumped over to produce the correct decimal result. You will be pleased to know that the 6510 will actually take care of this correction for you when it knows you are using BCD. But how does it know when you are using BCD? Well, you must flag the condition by setting the Decimal flag in the Status register with:

SED Set Decimal flag (D = 1)

The corresponding flag clearing instruction is:

CLD Clear Decimal flag (D = 0)

Program 13 uses immediate addressing to perform a BCD addition.

Program 13

```
10   REM * * SIMPLE BCD ADDITION * *
20   CODE = 49152
30   FOR LOOP = 0 TO 9
40      READ BYTE
50      POKE CODE + LOOP, BYTE
60   NEXT LOOP
70
80   REM * * M/C DATA * *
90   DATA 248           REM $F8         — SED
100  DATA 24            REM $18         — CLC
110  DATA 169,9         REM $A9, $09    — LDA #$09
120  DATA 105,5         REM $69, $05    — ADC #$05
130  DATA 133,251       REM $85, $FB    — STA $FB
```

```
140  DATA 216         REM $D8        — CLD
150  DATA 96          REM $60        — RTS
160
170  SYS CODE
180  PRINT PEEK (251)
```

As can be seen, BCD addition is no different from normal hex addition except for the three extra instructions SED, CLC and CLD. RUN the program. Unfortunately, the result is 20 and not 14 as we would expect. The reason for this is that the Kernal print routine interprets the byte stored at location 251 ($FB) as a hex one and not a BCD one. Don't believe me eh? Well, the hex for 20 is $14 (told you!). Writing this in binary form we have:

```
0001 0100
```

This, as you will now realize, is the BCD binary for 14 BCD.

Chapter 23 contains a program that will print decimal numbers in hex form—which is really what we're after. This program can be used to output correct BCD values.

Similarly, a BCD subtraction would take the form:

```
SED              \ set decimal mode
SEC              \ set Carry flag
LDA VALUE        \ get first value
SBC NUMBER       \ subtract a number
STA RESULT       \ save the result
CLD              \ clear decimal mode
```

One final important point to remember regarding the Carry flag—when using BCD, the Carry flag signals a result greater than 99 during addition.

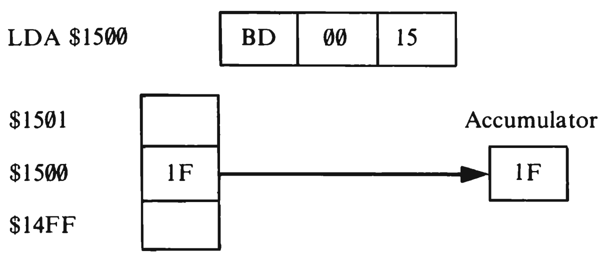
11 Addressing Modes II

Let us now take a second look at addressing modes. In the previous chapters we have seen how data can be obtained directly by an instruction using *immediate* addressing, or indirectly from a location in zero page using *zero page* addressing. We shall now see how two byte address locations can be accessed both directly and indirectly (through the all important zero page), and how whole blocks of memory can be manipulated using *indexed* addressing.

ABSOLUTE ADDRESSING

Absolute addressing works in exactly the same manner as zero page addressing, but it covers all memory locations outside zero page. The mnemonic is followed by two bytes which specify the address of the memory location (which can be anywhere in the range $100 to $FFFF).

Operation



As can be seen above, the operation code is followed by the address which, as always, is stored in reverse order low byte first. The contents of location $1500 are copied into the accumulator when the instruction is executed.

Program 14 uses absolute addressing to place a white A on to the screen; note that it is not printed but stored into screen memory.

Program 14

```
10  REM * * ABSOLUTE ADDRESSING * *
20  CODE = 49152
30  FOR LOOP = 0 TO 8
40     READ BYTE
50     POKE CODE + LOOP, BYTE
60  NEXT LOOP
```

```
80  REM * * M/C DATA * *
90  DATA 169,1          REM $A9, $01       — LDA #$01
100 DATA 141,80,04      REM $8D, $50, $04  — STA 1104
110 DATA 141,80,216     REM $8D, $50, $D8  — STA 55376
120 DATA 96             REM $60            — RTS
130
140 PRINT CHR$ (147)
150 PRINT : PRINT : PRINT
160 SYS CODE
```

The meaning of each line is as follows:

Lines 20–60	Assemble machine code.
Line 90	Load accumulator with display code for 'A' and colour code white.
Line 100	Store A into screen memory.
Line 110	Store white code into colour memory.
Line 120	Back to BASIC.
Lines 140–150	Clear screen and move cursor down.
Line 160	Execute machine code.

The complete list of instructions associated with absolute addressing is shown in Table 11.1.

Table 11.1

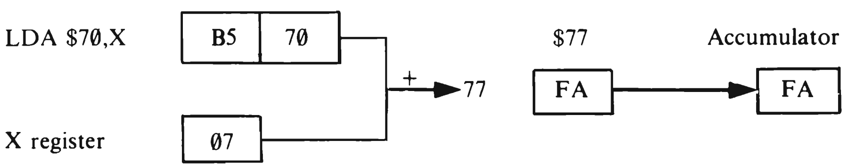
Absolute addressing instructions

ADC	Add with carry	LDA	Load accumulator
AND	Logical AND	LDX	Load X register
ASL	Arithmetic shift left	LDY	Load Y register
BIT	Bit test	LSR	Logical shift right
CMP	Compare accumulator	ORA	Logical OR
CPX	Compare X register	ROL	Rotate left
CPY	Compare Y register	ROR	Rotate right
DEC	Decrement memory	SBC	Subtract with carry
EOR	Logical EOR	STA	Store accumulator
INC	Increment memory	STX	Store X register
JMP	Jump	STY	Store Y register
JSR	Jump, save return		

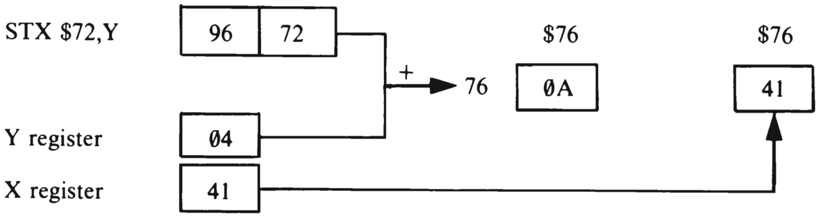
ZERO PAGE INDEXED ADDRESSING

In zero page indexed addresing, the actual address of the operand is calculated by adding the contents of either the X or Y register to the zero page address stated.

Operation:



The X register in this instance contains $Ø7. This is added to the specified address, $7Ø, to give the actual address, $77. The contents of location $77 (in this case FA) are then loaded into the accumulator. Similarly:



Here the Y register is used as an index to allow the contents of the X register to be stored in memory location $76. This address was obtained by adding the Y register's value, $Ø4, to the specified value, $72. The original contents of location $76 (ØA) are overwritten.

Note the Y register can *only* be used to operate on the X register with instructions such as LDX $FB, Y. The instructions associated with zero page indexing are listed in Table 11.2.

Table 11.2

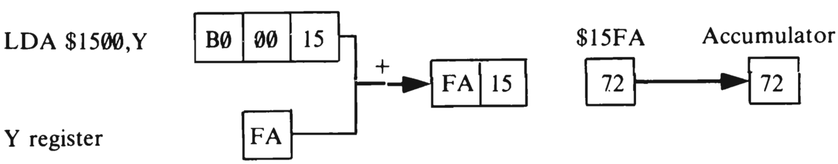
Zero page indexed addressing instructions			
ADC	Add with carry	LDY	Load Y register
AND	Logical AND	LSR	Logical shift right
ASL	Arithmetic shift left	ORA	Logical OR
CMP	Compare	ROL	Rotate left
DEC	Decrement memory	ROR	Rotate right
EOR	Logical EOR	SBC	Subtract with carry
INC	Increment memory	STA	Store accumulator
LDA	Load accumulator	*STX	Store X register
*LDX	Load X register	STY	Store Y register

The * indicates the only commands which can use the Y register as an index. All other commands are for X register only.

ABSOLUTE INDEXED ADDRESSING

Absolute indexed addressing is like zero page indexed addressing except that the locations accessed are outside zero page. The X and Y registers may be used as required to operate with the accumulator, or each other.

Operation:



The Y register's contents ($FA) are added to the two byte address ($15ØØ) to give effective address ($15FA).

The following program demonstrates how absolute indexed addressing can be used to move a section of screen memory from one location to another.

Program 15

```
 10 REM * * ABSOLUTE INDEXED ADDRESSING * *
 20 CODE = 49152
 30 FOR LOOP = 0 TO 21
 40    READ BYTE
 50    POKE CODE + LOOP, BYTE
 60 NEXT LOOP
 70
 80 REM * * M/C DATA * *
 90 DATA 162,32           REM $A2, $20          — LDX #$20
100 DATA 189,0,4          REM $BD, $00, $04     — LDA 1024, X
110 DATA 157,8,6          REM $9D, $08, $06     — STA 1544, X
120 DATA 202              REM $CA               — DEX
130 DATA 208,247          REM $D0, $F7          — BNE -9
140 DATA 169,1          : REM $A9, $01          — LDA #$01
150 DATA 162,32         : REM $A2, $20          — LDX #$20
160 DATA 157,8,218        REM $9D, $08, $DA     — STA 55816, X
170 DATA 202              REM $CA               — DEX
180 DATA 208,250        : REM $D0, $FA          — BNE -5
190 DATA 96               REM $60               — RTS
200
210 PRINT CHR$(147);
220 PRINT " ABSOLUTE INDEXED ADDRESSING"
230 GET A$
240 IF A$ = " " THEN GOTO 230
250 SYS CODE
```

The meaning of each line is as follows:

Lines 20–60	Assemble machine code.
Line 90	Sex X register count.
Line 100	Load accumulator with contents of location 1024 + X.
Line 110	Store accumulator's contents at 1544 + X.
Line 120	Decrement X register.
Line 130	IF X <> 0 then go back.
Line 140	Load accumulator with 1 (white colour code).
Line 150	Set X register count.
Line 160	Store code in colour memory, 55816 + X.
Line 170	Decrement X register.
Line 180	IF X <> 0 then go back.
Line 190	Back to BASIC.
Lines 210–220	Clear screen and print title.
Lines 230–240	Wait for a key to be pressed.
Line 250	Execute machine code.

When RUN, the message of line 220 is printed on to the screen. The program then waits for a key to be pressed before calling the machine code. The X register acts as the offset counter and is initialized in line 90. The byte at location 1024 + X is loaded into the accumulator, and then stored back into screen memory at 1544 + X; in both instances absolute indexed addressing is used. Two new instructions are introduced in lines 120 and 130 and these will be examined in the next couple of chapters. Briefly through, DEX decreases the contents of the X register by one, and BNE tests to see if the X register has reached zero. If X is not zero, the specified jump takes place, causing the load/store procedure to be repeated with the new value of X. Lines 150 to 180 work in a similar manner, storing the white colour code in the corresponding bytes of the colour memory. This, in effect, turns the letters 'on' so that they can be seen (see the *User Manual* for a description of this if you do not understand the procedure).

The instructions associated with absolute indexed addressing are shown in Table 11.3

Table 11.3

Absolute indexed addressing instructions			
*ADC	Add with carry	**LDX	Load X register
*AND	Logical AND	LDY	Load Y register
ASL	Arithmetic shift left	LSR	Logical shift right
*CMP	Compare memory	*ORA	Logical OR
DEC	Decrement memory	ROL	Rotate left
*EOR	Logical exclusive OR	ROR	Rotate right
INC	Increment memory	*SBC	Subtract with carry
*LDA	Load accumulator	*STA	Store accumulator

Unmarked commands are available with X register as index only. Commands marked * may use either register, whereas the one marked ** can only use the Y register.

INDIRECT ADDRESSING

Indirect addressing allows us to read or write to a memory address which is not known at the time of writing the program! Crazy? Not really, the program itself may calculate the actual address to be handled. Alternatively, a program may contain within it several tables of data which are all to be manipulated in a similar manner. Rather than writing a separate routine for each, a general purpose one can be developed, with the address operand being '*seeded*' on each occasion the routine is called.

Indirect addressing's beauty is that it enables the whole of the Commodore's memory map to be accessed with a single two byte instruction. To distinguish indirect addressing from other addressing modes, the operands must be enclosed in brackets.

Pure indexed addressing in only available to one instruction—the jump instruction—which is mnemonically represented by JMP. We will look at JMP's function in more detail during the course of Chapter 14, but suffice to say for now that it is the 6510's equivalent of BASIC's GOTO statement. (Though it does of course jump to an address rather than a line number.)

A typical indirect jump instruction takes the form:

```
DATA 108, 251, 00 : REM $6C, $FB, $00 — JMP ($FB)
```

The address specified in the instruction is not the address jumped to, but is the address of the location where the jump address is stored. In other words, don't jump here but to the address stored here!

Operation:

JMP ($FB)	6C	FB	00

$FD	
$FC	FF
$FB	DA

From the operational example we can see that location $FB contains the low byte of the address, and location $FC the high byte. These two locations, which act as temporary stores for the address, are known as a *vector*. Executing JMP ($FB) in this instance will cause the program to jump to the location $FFDA.

Program 16 illustrates the use of an indirect JMP to fill the screen with stars.

Program 16

```
10  REM * *INDIRECT JUMPING * *
20  CODE = 49152
30  FOR LOOP = 0 TO 15
40      READ BYTE
50      POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 169,0          REM $A9, $00        — LDA #$00
100 DATA 133,251        REM $85, $FB        — STA $FB
110 DATA 169,192        REM $A9, $C0        — LDA #$C0
120 DATA 133,252        REM $85, $FC        — STA $FC
130 DATA 169,42         REM $A9, $2A        — LDA #ASC"*"
140 DATA 32,210,255     REM $20, $D2, $FF   — JSR $FFD2
150 DATA 108,251,0      REM $6C, $FB, $00   — JMP ($FB)
160
170 SYS CODE
```

Lines 90 to 120 set up a vector in zero page. Two of the free user bytes are loaded with the assembly address of the machine code, $C000 in this case. Line 130 places the ASCII code for the asterisk into the accumulator, and this is printed out using the Kernal routine at $FFD2 (line 140). Finally the routine jumps back to the start via the zero page vector (line 150).

JMP ($FB)	6C	FB	00

$FC	C0	Jump to $C000
$FB	00	

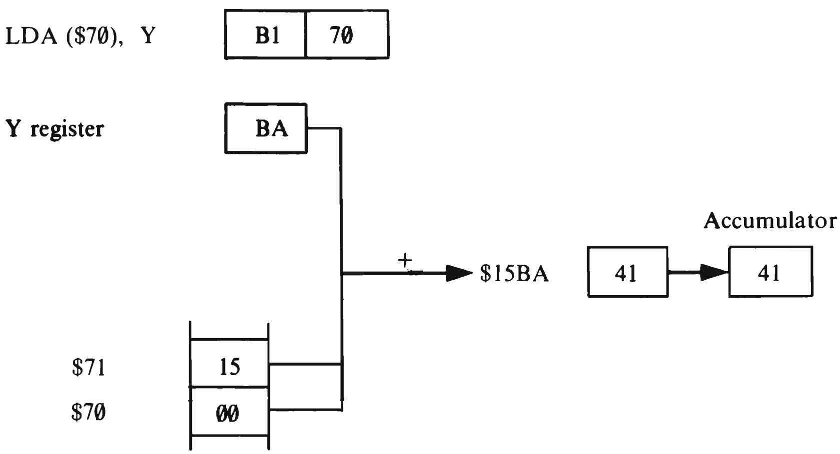
The program is now in a continuous loop and will carry on printing stars *ad infinitum*. I'm afraid pressing the STOP key has no effect—that's for BASIC only; you'll have to switch off at the side and then back on again to return to any semblance of normality!

The Commodore 64 itself uses indirect addressing extensively. If you flip to page 114 you'll see a list of Kernal routines which, when called, perform indirect jumps into the depths of the Operating System via vectors in block zero RAM.

POST-INDEXED INDIRECT ADDRESSING

Post-indexed addressing is a little like absolute indexed addressing, but in this case, the base address is stored in a zero page vector which is accessed indirectly.

Operation:



In the example above, the base address is stored in the vector at $70 and $71. The contents of the Y register ($BA) are added to the address in the vector ($1500) to give the actual address ($15BA) of the data. It should be obvious that this form of indirect addressing allows access to a 256 byte range of locations. In the case above, any location from $1500 and $15FF is available by setting the Y register accordingly.

Program 17 uses post-indexed indirect addressing to move a line of screen memory from the upper to the lower half of the screen.

Program 17

```
10  REM * * INDIRECT ADDRESSING * *
20  CODE = 49152
30  FOR LOOP = 0 TO 19
40      READ BYTE
50      POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 160,39         REM $A0, $27         — LDY #$27
```

```
100  DATA 177,251      REM $B1, $FB        — LDA ($FB), Y
110  DATA 145,253      REM $91, $FD        — STA ($FD), Y
120  DATA 136          REM $88             — DEY
130  DATA 208,249      REM $DØ, $F9        — BNE -7
140  DATA 162,39       REM $A2, $27        — LDX #$27
150  DATA 169,1        REM $A9, $Ø1        — LDA #$Ø1
160  DATA 157,8,218    REM $9D, $Ø8, $DA   — STA 55816, X
170  DATA 202          REM $CA             — DEX
180  DATA 208,250      REM $DØ, $FA        — BNE - 6
190  DATA 96           REM $6Ø             — RTS
200
210  POKE 251,Ø :  POKE 252,4 : REM SCREENTOP
220  POKE 253,8 :  POKE 254,6 : REM SCREENBOT
230  PRINT CHR$(147);
240  PRINT " INDIRECT INDEXED ADDRESSING"
250  GET A$
260  IF A$ = " " THEN GOTO 250
270  SYS CODE
```

The program commences by assembling the machine code held in the data statements. Next, two vectors are created in zero page. The first (line 21Ø) is POKEd with the address of the top left-hand corner of the screen (1Ø24) and is called SCREENTOP. Similarly, in line 22Ø, the next two locations are seeded to point to SCREENBOT (1544).

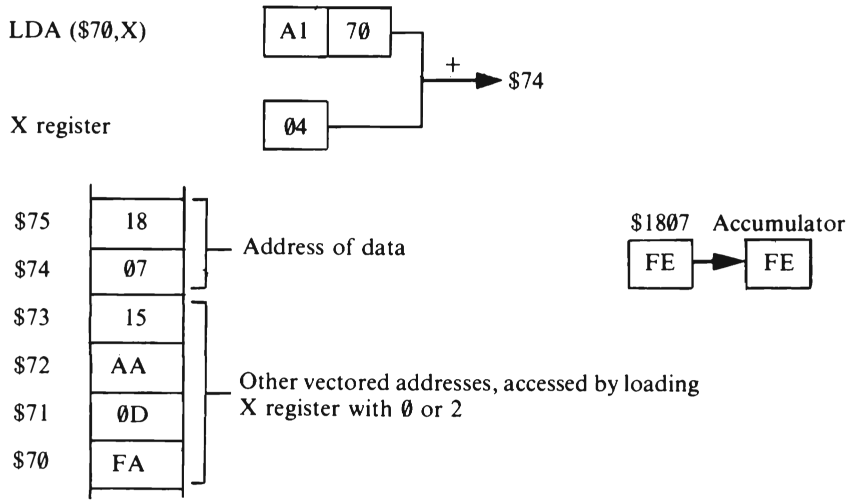
Once the program title has been printed and a key has been pressed, the machine code stored in the 'free' RAM area is executed. The Y register is set to the text screen line length count (line 9Ø), then using post-indexed indirect addressing, the byte stored at SCREENTOP + Y is loaded into the accumulator (line 1ØØ) and stored in screen memory at the location specified by SCREENBOT + Y (line 11Ø). The Y register is decremented, thus allowing the next location to be accessed (line 12Ø), and the process repeated until the Y register holds Ø (the BNE instruction in line 13Ø takes care of this, as we shall see in the next chapter).

The character codes for the title at the top of the screen are now stored in memory midway down the screen. To make them visible, the corresponding locations in the colour memory (from 55816) must be POKEd with the relevant colour code. This is taken care of in lines 14Ø–19Ø. Line 14Ø begins by initializing the X register to the line length, and the colour code is then loaded into the accumulator (line 15Ø). Colour code '1' means that the text will appear white. Once again, the DEX and BNE (lines 18Ø and 19Ø) are used to control the number of times this piece of code is repeated.

PRE-INDEXED ABSOLUTE ADDRESSING

This addressing mode is used if we wish to indirectly access a whole series of absolute addresses which are stored in zero page.

Operation:



Here the contents of the X register ($04) are added to the zero page address ($70) to give the vector address ($74). The two bytes here are then interpreted as the actual address of the data ($1807).

Setting the X register to $02 gives indirect access to the vector address $15AA.

A list of instructions which can be used with pre- and post-indexed addressing is shown in Table 11.4.

Table 11.4

Pre- and post-indexed indirect addressing instructions	
ADC	Add with carry
AND	Logical AND
CMP	Compare memory
EOR	Logical exclusive OR
LDA	Load accumulator
ORA	Logical OR
SBC	Subtract with carry
STA	Store accumulator

IMPLIED AND RELATIVE ADDRESSING

Two other modes of addressing are available with the 6510 namely, *implied* addressing and *relative* addressing. We will be dealing with both of these addressing modes during the course of the next few chapters.

12 Stacks of Fun

THE STACK

The stack is perhaps one of the more difficult aspects of the 651Ø to understand, however it is well worth the time mastering as it lends itself to more efficient programming. Because of its importance the whole of *Page $Ø1* (that is memory locations $1ØØ through to $1FF) is given over to its operation.

The stack is used as a temporary store for data and memory addresses that need to be remembered for use sometime later on during the program. For most purposes its operation is transparent to us. For example, when, during the course of a BASIC program a GOSUB is performed, the address of the next BASIC command or statement after it is placed onto the stack, so that the program knows where to return to on completion of the procedure. The process of placing values onto the stack is known as *pushing,* whilst retrieving the data is called *pulling.*

The stack has one important feature which must be understood—it is a *last in, first out* (LIFO) structure. What this means is that the last byte pushed onto the stack must be the first byte pulled from it.

A useful analogy to draw here is that of a train yard. Consider a small spur line, onto which trucks 1, 2 and 3 are pushed (see Figure 12.1). The first truck onto the line (truck 1) is at the very end of the line, truck 2, the second onto the line is in the middle, and the last truck (truck 3) is nearest the points.

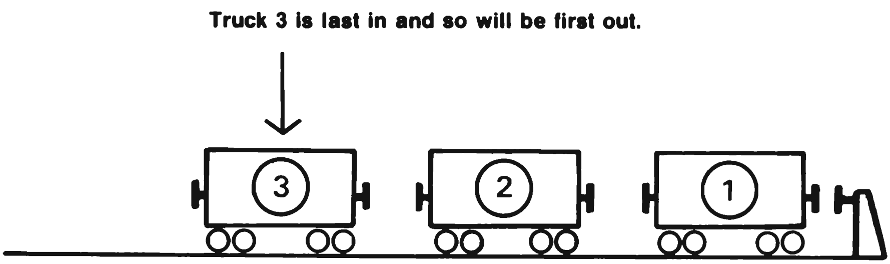


Figure 12.1 The stack—LIFO.

It should now be fairly obvious that the first truck to be pulled off the spur must be the last truck pushed onto it, that is, truck 3. Truck 2 will be the next to be pulled from the line, and the first truck in will be the last one out.

To help us keep track of our position on the stack, there is a further 651Ø register called the *Stack Pointer.* Because the stack is a hardware item of the 651Ø, that is, it is actually 'wired' into it, the 'page number' of the stack ($Ø1) can be omitted from the address, and the Stack Pointer just points to the next free position in the stack.

When the Commodore 64 is switched on (or a BREAK is performed) the Stack Pointer is loaded with the value $FF—it points to the top of the stack—this means that the stack grows down the memory map rather than up as may be expected. Each time an item is pushed the Stack Pointer is decremented, and conversely, it is incremented when the stack is pulled.

STACK INSTRUCTIONS FOR SAVING DATA

The 6510 has four instructions that allow the accumulator and Status register to be pushed and pulled. They are:

PHA	Push accumulator onto stack
PLA	Pull accumulator from stack
PHP	Push Status register onto stack
PLP	Pull Status register from stack

All four instructions use *implied* addressing and occupy only a single byte of memory.

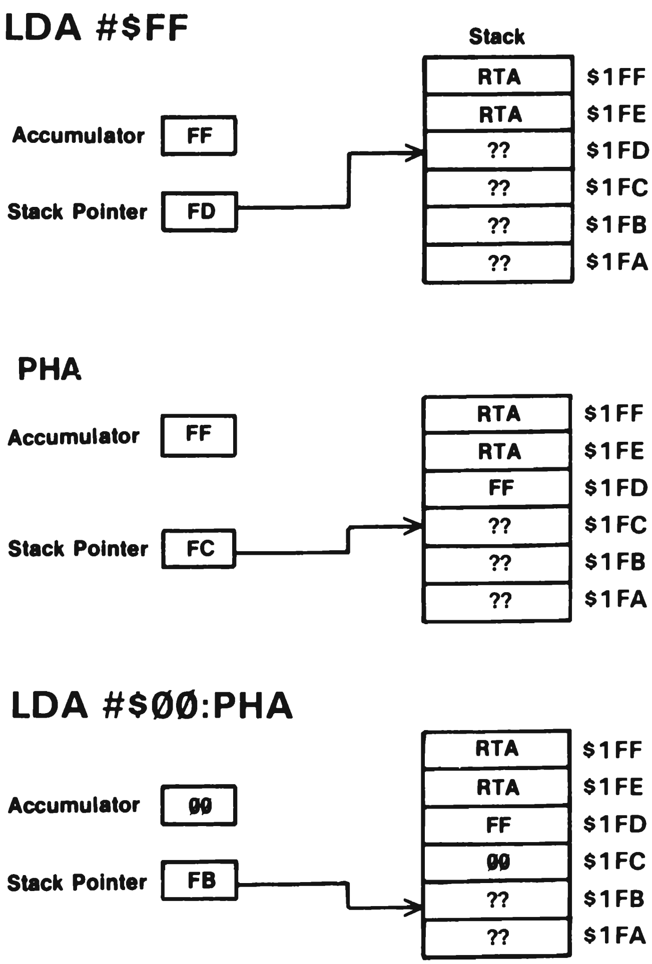


Figure 12.2 Pushing items on to the stack.

The PHA and PHP instructions work in a similar manner, but on different registers. In both cases the source register remains unaltered by the instruction. Again PLA and PLP are similar in operation, but PLA conditions only the Negative and Zero flags, while PLP of course conditions all the flags.

Consider the following sequence of instructions:

```
TWOPUSH  LDA #$FF          \ place $FF in accumulator
         PHA               \ push onto stack
         LDA #$00          \ place $00 in accumulator
         PHA               \ push onto stack
```

Figure 12.2 shows exactly what happens as this program is executed. The Stack Pointer (SP) at the start contains $FD and points to the next free location in the stack. The first two stack locations $FF and $FE hold the two byte return address (RTA) to which the machine code will eventually pass control. (This may be the address of the next BASIC instruction if a call to machine code has been made.) The subsequent stack locations are at present undefined and are therefore represented as ??.

After the accumulator has been loaded with $FF it is copied onto the stack by PHA. Note that the accumulator's contents are not affected by this operation. Once it has been pushed onto the stack, the Stack Pointer's value is decremented by one to point to the next free location in the stack ($FC).

The accumulator is then loaded with $00 and this is pushed on to the stack at location $FC. The Stack Pointer is again decremented to the next free location ($FB).

To remove these items from the stack the following could be used:

```
TWOPULL  PLA               \ get $00 from stack
         STA TEMP          \ save it somewhere
         PLA               \ get $FF from stack
         STA TEMP + 1      \ save it as well
```

Figure 12.3 illustrates what happens in this case. The first PLA will pull from the stack into the accumulator the last item pushed onto it, which in this example is $00. The Stack Pointer is incremented, this time to point to the new 'next free location', $FC. As you can see from the diagram the stack contents are not altered, but the $00 will be overwritten if a further item is now pushed. The STA TEMP saves the accumulator value somewhere in memory so that it is not destroyed by the next PLA. This PLA restores the value $FF into the accumulator, and again increments the Stack Pointer.

One thing should now be apparent—it is very important to remember the order in which items are pushed onto the stack, as they *must* be pulled in exactly the reverse order. If this process is not strictly adhered to then errors will certainly result, and could even cause your program to crash or hang-up!

The following program shows how the stack can be used to save the contents of the various registers to be printed later. This is particularly useful for debugging those awkward programs that just will not work.

```
REGSAVE  PHP               \ save Status register
         PHA               \ save accumulator
         TXA               \ transfer X into accumulator
         PHA               \ save accumulator (X)
         TYA               \ transfer Y into accumulator
         PHA               \ save accumulator (Y)
```

It is important to save the registers in the order shown. The Status register should be saved first so that it will not be altered by the subsequent transfer instructions which could affect the Negative and Zero flags, and the accumulator must be saved before its value is destroyed by either of the index register transfer operations.

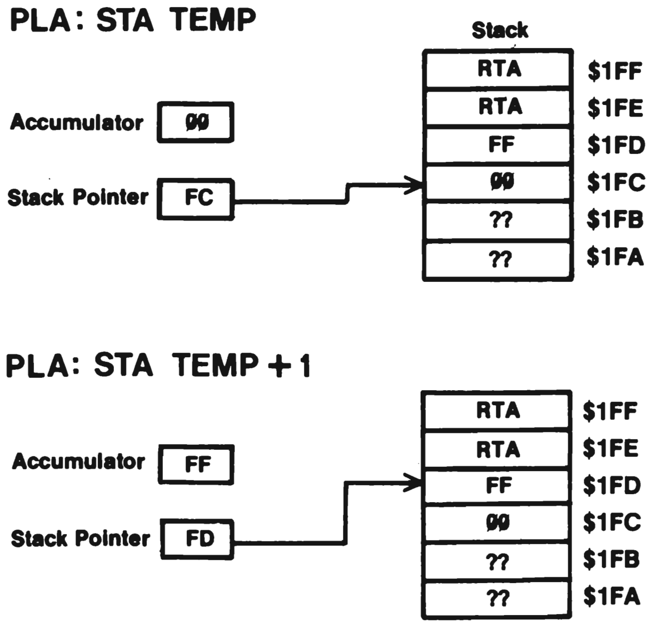


Figure 12.3 Pulling items from the stack.

If the registers' values had been saved to preserve them while another portion of the program was operating, we could retrieve them with:

```
PLA        \ pull accumulator (Y)
TAY        \ and transfer to Y register
PLA        \ pull accumulator (X)
TAX        \ and transfer to X register
PLA        \ pull accumulator
PLP        \ pull Status register
```

There are two final stack associated instructions:

TSX Transfer Stack Pointer to X register

TXS Transfer X register to Stack Pointer

These instructions allow the Stack Pointer to be seeded as required. On power-up or BREAK the Commodore does the following:

```
LDX #$FF   \ load X with $FF
TXS        \ place in Stack Pointer
```

It is very unlikely that you will ever need these two instructions unless you go on to such splendid projects as writing your own interpreter!

We shall see how and why the stack is used to save addresses in Chapter 14.

13 Looping

LOOPS

Loops allow sections of programs to be repeated over and over again. For example, in BASIC we could print ten exclamation marks using a FOR . . . NEXT loop like this:

```
10  FOR NUMBER = 0 TO 9
20  PRINT "!" ;
30  NEXT NUMBER
```

In line 10 a counter called NUMBER is declared and initially set to zero. Line 20 prints the exclamation mark, and line 30 checks the present value of NUMBER to see if it has reached its maximum limit. If it has not, the program adds one to NUMBER and branches back to print the next exclamation mark.

To implement this type of loop in assembly language we need to know how to control and use the three topics identified above; namely counters, comparisons and branches.

COUNTERS

It is usual to use index registers as counters, because they have their own increment and decrement instructions.

INX	Increment X register	X = X + 1
INY	Increment Y register	Y = Y + 1
DEX	Decrement X register	X = X − 1
DEY	Decrement Y register	Y = Y − 1

All these instructions can affect the Negative and Zero flags. The Negative flag is set if the most significant bit of the register is set following an increment or decrement instruction—otherwise it will be cleared. The Zero flag will only be set if any of the instructions cause the register concerned to contain zero.

Note that incrementing a register which contains $FF will reset that register to $00, will clear the Negative flag (N = 0) and will set the Zero flag (Z = 1). Conversely, decrementing a register holding $00 will reset its value to $FF, set the Negative flag and clear the Zero flag.

There are two other increment and decrement instructions:

INC	Increment memory
DEC	Decrement memory

These instructions allow the values in memory locations to be adjusted by one, for example:

```
INC $70          \ add 1 to location $70
DEC $1500        \ subtract 1 from location $1500
```

Both instructions condition the Negative and Zero flags as described earlier.

Program 18 shows how these instructions can be used, in this case to print 'ABC' on the screen.

Program 18

```
10  REM * * INCREMENTING A REGISTER * *
20  CODE = 49152
30  FOR LOOP = 0 TO 16
40    READ BYTE
50    POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 169,65           REM $A9, $41          — LDA #ASC"A"
100 DATA 170            : REM $AA               — TAX
110 DATA 232            : REM $E8               — INX
120 DATA 32,210,255     : REM $20, $D2, $FF     — JSR $FFD2
130 DATA 138            : REM $8A               — TXA
140 DATA 232            : REM $E8               — INX
150 DATA 32,210,255     : REM $20, $D2, $FF     — JSR $FFD2
160 DATA 138            : REM $8A               — TXA
170 DATA 32,210,255     : REM $20, $D2, $FF     — JSR $FFD2
180 DATA 96             : REM $60               — RTS
190
200 SYS CODE
```

The meaning of each line is as follows:

Lines 20–60	Assemble machine code.
Line 90	Place ASCII 'A' in accumulator.
Line 100	Save it in X register.
Line 110	Increment X to give code for 'B'.
Line 120	Print 'A' to screen.
Line 130	Transfer ASCII code for 'B' to accumulator.
Line 140	Increment X to give code for 'C'.
Line 150	Print 'B' to screen.
Line 160	Transfer ASCII code for 'C' into accumulator.
Line 170	Print 'C' to screen.
Line 180	Back to BASIC.
Line 200	Execute machine code.

COMPARISONS

There are three compare instructions:

CMP	Compare accumulator
CPX	Compare X register
CPY	Compare Y register

The contents of any register can be compared with the contents of a specified memory location, or as is often the case, the value immediately following the mnemonic. The values being tested remain unaltered. Depending on the result of the comparison, the Negative, Zero and Carry flags are conditioned. How are these flags conditioned? Well, the first thing the 651Ø does is set the Carry flag (C = 1). It then subtracts the specified value from the contents of the register. If the value is less than, or equal to the register contents, the Carry flag remains set. If the two values are equal the Zero flag is also set. If the Carry flag has been cleared, it means that the value was greater than the register contents, and a borrow occurred during the subtraction. The Negative flag is generally (but not always) set when this occurs—this is only really valid for two's complement compares. Table 13.1 summarizes these tests.

Table 13.1

Test	Flags		
	C	Z	N
Register less than data	Ø	Ø	1
Register equal to data	1	1	Ø
Register greater than data	1	Ø	Ø

BRANCHES

Depending on the result of a comparison, the program will need either to branch back to repeat the loop, branch to another point in the program, or just simply continue. This type of branching is called *conditional branching,* and eight instructions enable various conditions to be evaluated. The branch instructions are:

BNE	Branch if not equal	Z = Ø
BEQ	Branch if equal	Z = 1
BCC	Branch if Carry clear	C = Ø
BCS	Branch if Carry set	C = 1
BPL	Branch if plus	N = Ø
BMI	Branch if minus	N = 1
BVC	Branch if overflow clear	V = Ø
BVS	Branch if overflow set	V = 1

Let's now rewrite the BASIC program to print ten exclamation marks (see page 62) in assembly language.

Program 19

```
10  REM * * 10 ! MARKS * *
20  CODE = 49152
```

```
30  FOR LOOP = 0 TO 12
40    READ BYTE
50    POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 162,0          : REM $A2, $00          — LDX #0
100 DATA 169,33         : REM $A9, $21          — LDA #ASC"!"
110 DATA 32,210,255     : REM $20, $D2, $FF     —JSR $FFD2
120 DATA 232            : REM $E8               — INX
130 DATA 224,10           REM $E0, $0A          — CPX #10
140 DATA 208,248        : REM $D0, $F8          — BNE -8
150 DATA 96             : REM $60               — RTS
160
170 SYS CODE
```

Lines 90 and 100 initialize the X register and place the ASCII code for an exclamation mark into the accumulator. Line 110 uses the JSR instruction to print the accumulator's contents to the screen. The X register is incremented (line 120) and if not yet equal to 10 the BNE instruction (line 140) is performed and the program loops back to print another exclamation mark.

If you look closely at the program listing, more especially at line 140, you will notice that the BNE opcode is followed by a single byte, and not an address as you may have expected. This byte is known as the *displacement,* and this type of addressing is called *relative* addressing. The operand, in this case 248 ($F8), tells the processor that a backward branch of 8 bytes is required.

To distinguish branches backwards from branches forward you use *signed binary.* A negative value indicates a backward branch while a positive number indicates a forward branch. Obviously, it is important to know how to calculate these displacements—so let's try it.

Before sitting down in front of your Commodore 64 it is always best to write out your machine code program on paper. While it is perfectly feasible to write it 'at the keyboard', this nearly always leads to problems caused by errors in the coding (and I speak from experience). To make it clear just where loops are branching to and from, you can use *labels.* Table 13.2 shows the layout for Program 19.

Table 13.2

Label	Mnemonics	Comments
START		Code begins
	LDX #0	Loop counter
	LDA #ASC "!"	ASCII code for '!'
LOOP		Branch destination
	JSR $FFD2	Print'!'
	INX	X = X + 1
	CPX #10	Is X = 10 yet?
	BNE LOOP	No, continue
	RTS	All done!

To calculate the branch displacement, just count the number of bytes from the displacement byte itself *back* to the label LOOP.

```
LOOP
         JSR $FFD2     3 bytes
         INX           1 byte
         CPX #10       2 bytes
         BNE LOOP      2 bytes
```

This gives a total displacement of 8 bytes. Note that the relative displacement and the BNE opcode are included in the count because the Program Counter will be pointing to the instruction *after* the branch.

To convert this backward displacement into its signed binary form, you just calculate its two's complement value (see Chapter 3 if you need some refreshing on how to do this).

```
   0000 1000   (8)
   1111 0111
+          1
   ---------
   1111 1000   (-8 = $F8)
```

Since all branch instructions are two bytes long, effective displacements of −126 bytes (−128 + 2) and +129 bytes (127 + 2) are possible.

To make life easier, you'll be relieved to know that Appendix 6 contains a couple of tables from which you can read off displacement values directly.

To demonstrate the use of a forward branch enter and RUN Program 20 which displays a 'Y' if location $FB contains a '0' or an 'N' otherwise.

Program 20

```
10  REM * * FORWARD BRANCHING * *
20  CODE = 49152
30  FOR LOOP = 0 TO 14
40    READ BYTE
50    POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 165,251       REM $A5, $FB        — LDA $FB
100 DATA 240,6         REM $F0, $06        — BEQ ZERO
110 DATA 169,78        REM $A9, $4E        — LDA #ASC"N"
120                    REM BACK
130 DATA 32,210,255    REM $20, $D2, $FF   — JSR $FFD2
140 DATA 96            REM $60             — RTS
150                    REM ZERO
160 DATA 169,89        REM $A9, $59        — LDA #ASC"Y"
170 DATA 24            REM $18             — CLC
180 DATA 144,247       REM $90, $F7        — BCC BACK
```

```
190
200  SYS CODE
```

In this program I have used labels contained within REM statements to identify the jump addresses. This should help to make things clearer.

The machine code begins by loading the byte at location $FB into the accumulator. If the byte is zero this will automatically set the Zero flag, and the branch of line 100 will be executed (BEQ—branch if equal). Because this is a forward branch a positive value is used to indicate the displacement—in this instance 6 bytes forward. The accumulator is then loaded with the ASCII code for Y. If the contents of $FB are non-zero, then the BEQ fails and the accumulator is loaded with 'N'.

Lines 170 and 180 illustrate a technique known as *forced branching.* The Carry flag is cleared and a BCC (branch carry clear) executed—because we cleared the Carry flag beforehand we have *forced* the processor to jump to BACK.

Whenever a register is used as a loop counter, and *only* as a loop counter, it is better to write the machine code so that the register counts down rather than up. Why? Well, you may recall from Chapter 7 that when a register is decremented such that it holds zero the Zero flag is set. Using this principle Program 19 can be re-written as follows, so that the CPX #10 instruction is superfluous:

Program 21

```
 10  REM * * DOWN COUNT * *
 20  CODE = 49152
 30  FOR LOOP = 0 TO 10
 40    READ BYTE
 50    POKE CODE + LOOP, BYTE
 60  NEXT LOOP
 70
 80  REM * * M/C DATA * *
 90  DATA 162,10         REM $A2, $0A       — LDX #10
100  DATA 169,33         REM $A9, $21       — LDA #ASC"!"
110                      REM LOOP
120  DATA 32,210,255   : REM $20, $D2, $FF  — JSR $FFD2
130  DATA 202            REM $CA            — DEX
140  DATA 208,250      : REM $D0, $FA       — BNE LOOP
150  DATA 96           : REM $60            — RTS
160
170  SYS CODE
```

FOR . . . NEXT

In BASIC the FOR . . . NEXT loop makes the Commodore 64 execute a set of statements a specified number of times. All FOR . . . NEXT loops—including those containing positive and negative STEP sizes—are relatively easy to produce in machine code, and each type is summarized below.

1. FOR LOOP = FIRST TO SECOND . . . NEXT

This loop requires only two variables, the start and end values normally termed the entry and exit conditions. Here they are defined by the two variables FIRST and SECOND. No STEP size is indicated therefore the loop will increment by one each time round. In assembler this is implemented as:

```
SETUP   LDX FIRST           \ place loop start into counter
LOOP                        \ mark loop entry
        ...                 \ loop statements here
        INX                 \ add one to counter
        CPX SECOND          \ has loop limit been reached?
        BNE LOOP            \ no, execute loop again
```

2. FOR LOOP = SECOND TO FIRST STEP −1 . . . NEXT

This loop is essentially the same as the previous one, except that the counter must initially be loaded with SECOND, and then decremented by one each time round to mimic the STEP −1 statement.

```
SETUP   LDX SECOND          \ place loop start in counter
LOOP                        \ mark loop entry
        ...                 \ loop statements here
        DEX                 \ decrement counter
        CPX FIRST           \ finished?
        BCS LOOP            \ no, execute again
```

In this loop the Carry flag remains set until the loop count is decremented below FIRST. Therefore, if SECOND = 10 and FIRST = 6 the loop is executed 5 times, just as it would be in BASIC.

3. FOR LOOP = FIRST TO SECOND STEP 3 . . . NEXT

This loop is similar to that described in 1, except that three INX instructions are required to produce the STEP 3.

```
SETUP   LDX FIRST           \ place loop start in counter
LOOP                        \ loop entry
        ...                 \ execute loop statements here
        INX                 \ increment counter by 3
        INX
        INX
        CPX SECOND          \ finished?
        BNE LOOP            \ no, go again
```

On reaching SECOND the CPX instruction will succeed, setting the Zero flag. The BNE LOOP will fail and the loop is completed.

4. FOR LOOP = SECOND TO FIRST STEP −3 . . . NEXT

This loop is similar to that already described in 2, but needs three DEX instructions to generate the STEP −3.

```
SETUP   LDX SECOND          \ place loop start in counter
LOOP                        \ loop entry
```

```
        . . .                \ execute loop statements
        DEX                  \ decrement by three
        DEX
        DEX
        CPX FIRST            \ finished?
        BCS LOOP             \ no, go again
```

5. FOR LOOP = FIRST TO SECOND STEP NUM . . . NEXT

If NUM is known at the time of writing the program then just include the correct number of INX statements. However, if NUM = 10, ten INX instructions would be a pretty inefficient piece of programming. The rule here is to use INX for STEPs of 4 or less and otherwise to use the ADC instruction.

```
SETUP   LDX FIRST
LOOP
        . . .
        PHA                  \ save accumulator if needed
        TXA                  \ move counter across into
                               accumulator
        CLC                  \ clear Carry flag
        ADC NUM              \ add STEP size
        TAX                  \ restore counter
        PLA                  \ and accumulator
        CPX SECOND           \ finished?
        BNE LOOP             \ no, go again
```

Note here that the counter's contents must be transferred to the accumulator for the ADC NUM instruction to be performed, and returned to the X register on completion. If the accumulator's contents are important they can be preserved on the stack.

6. FOR LOOP = SECOND TO FIRST STEP −NUM . . . NEXT

The rules for 5 apply here, except that the Carry flag must first be set and SBC used to mimic the minus STEP size.

```
SEPUP   LDX SECOND
LOOP
        . . .
        PHA                  \ save accumulator if needed
        TXA                  \ move counter across
        SEC                  \ get Carry flag
        SBC NUM              \ minus STEP
        TAX                  \ restore counter
        PLA                  \ and accumulator
        CPX FIRST            \ finished?
        BCS LOOP             \ no, go again
```

Of course, the Y register could have been used equally well as the loop counter.

MEMORY COUNTERS

Invariably programs that operate on absolute addresses will require routines that are capable of incrementing or decrementing these double byte values. A typical case being a program using post-indexed indirect addressing that needs to sequentially access a whole range of consecutive memory locations. The following two programs show how this can be done. First, incrementing memory addresses.

Program 22

```
 10 REM * * INCREMENTING MEMORY * *
 20 CODE = 49152
 30 FOR LOOP = 0 TO 6
 40    READ BYTE
 50    POKE CODE + LOOP, BYTE
 60 NEXT LOOP
 70
 80 REM * * M/C DATA * *
 90 DATA 230,251     :  REM $E6, $FB     — INC $FB
100 DATA 208,2       :  REM $D0, $02     — BNE OVER
110 DATA 230,252     :  REM $E6, $FC     — INC $FC
120                     REM OVER
130 DATA 92             REM $60          — RTS
140
150 POKE 251, 0 : POKE 252, 0
160 SYS CODE
170 LOW = PEEK(251)
180 HIGH = PEEK(252)
190 NUM = HIGH * 256 + LOW
200 PRINT NUM
210 GOTO 160
```

Lines 90 to 120 contain the relevant code. Each time it is executed by the SYS CODE call (line 160) the low byte of the counter at $FB is incremented. When the low byte changes from $FF to $00 the Zero flag is set, and so the branch in line 100 will *not* take place allowing the high byte of the counter at $FC to be incremented.

Decrementing a counter is a little less straightforward.

Program 23

```
 10 REM * * DECREMENTING MEMORY * *
 20 CODE = 49152
 30 FOR LOOP = 0 TO 8
 40    READ BYTE
 50    POKE CODE + LOOP, BYTE
 60 NEXT LOOP
 70
```

```
80  REM * * M/C DATA * *
90  DATA 165,251       REM $A5, $FB      — LDA $FB
100 DATA 208,2       : REM $D0, $02      — BNE LSBDEC
110 DATA 198,252       REM $C6, $FC      — DEC $FC
120                    REM LSBDEC
130 DATA 198,251     : REM $C6, $FB      — DEC $FB
140 DATA 96          : REM $60           — RTS
150
160 POKE 251,0 : POKE 252,0
170 SYS CODE
180 LOW = PEEK(251)
190 HIGH = PEEK(252)
200 NUM = HIGH *  256 + LOW
210 PRINT NUM
220 GOTO 170
```

First, the accumulator is loaded with the low byte of the counter, $FB (line 90); this procedure will condition the Zero flag. If it is set, the low byte of the counter must contain $00, and therefore the high byte needs to be decremented (line 110)—the low byte of the counter will always be decremented (line 130).

If all registers are being used the following alternative can be employed:

```
          INC COUNTER
          DEC COUNTER
          BNE LSBDEC
          DEC COUNTER + 1
LSBDEC    DEC COUNTER
```

The process of first incrementing and then decrementing the low byte of COUNTER will condition the Zero flag in the same manner as a *load* instruction.

14 Subroutines and Jumps

SUBROUTINES

If you are familiar with BASIC's GOSUB and RETURN statements you should have little difficulty understanding the two assembler equivalents:

JSR   Jump save return

RTS   Return from subroutine

If you are not familiar, I will explain.

Quite often during the course of writing a program you will find that a specific operation must be performed more than once, perhaps several times. Rather than typing in the same group of mnemonics on every occasion, which is both time consuming and increases the programs' length, they can be entered once, out of the way of the main program flow, and called when required. Not every piece of repetitive assembler warrants being coded into a subroutine, however. For example:

INX : DEY : STA Temp

is quite common (or something very similar) however, when assembled it only occupies four bytes of memory, which is the same memory requirement as a JSR . . . RTS call. Nothing is to be gained by introducing a subroutine here then, in fact, it will actually slow the program operation down by a few millionths of a second! On the other hand:

CLC : LDA Temp : ADC Value : STA Somewhere

might well warrant its own subroutine call as, if absolute addressing is employed, it may be up to ten bytes in length.

Let's now look at a short program, which contains several subroutine calls to the Commodore 64's Kernal.

Program 24

```
10  REM * * SUBROUTINE DEMO * *
20  CODE = 49152
30  FOR LOOP = 0 TO 14
40    READ BYTE
50  : POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90                      REM WAIT
100 DATA 32,228,255     REM $20, $E4, $FF   — JSR $FFE4
110 DATA 240,251      : REM $F0, $FB        — BEQ WAIT
```

```
120  DATA 133,251      : REM $85, $FB       — STA $FB
130  DATA 230,251      : REM $E6, $FB       — INC $FB
140  DATA 165,251      : REM $A5, $FB       — LDA $FB
150  DATA 32,210,255     REM $20, $D2, $FF  — JSR $FFD2
160  DATA 96           : REM $60            — RTS
170
180  SYS CODE
```

This program uses two subroutine calls. The first (line 100) is to the Kernal GETIN subroutine at 65508 ($FFE4) which is, in effect, a keyboard scan routine. A full description of this routine (and all other Kernal routines) can be found in Chapter 20, but briefly this routine returns a detected key's ASCII value in the accumulator. If no keypress is detected then the accumulator holds 0. Line 110 tests the accumulator for zero, branching back to the GETIN routine until a keypress *is* detected. Then the key's code is stored in location 251 ($FB) and is incremented (line 130) before being loaded back into the accumulator. Finally, the CHROUT subroutine, which we have used several times before, is called to print the accumulator's contents to the screen. RUN the program to see the effect. Try pressing the 'A' key—a 'B' should be printed!

Now that we have taken a general overview of subroutine calls and their functions it will be useful to see just how they manage to do what they do.

The two instructions JSR and RTS must perform three functions between them. Firstly, the current contents of the Program Counter must be saved so that control may be returned to the calling program at some stage. Secondly, the 6510 must be told to execute the subroutine once it arrives there. Finally, program control must be handed back to the calling program.

The JSR instruction performs the first two requirements. To save the return address it pushes the two byte contents of the Program Counter onto the stack. The Program Counter at this stage will hold the address of the location containing the third byte of the three which constitute the JSR instruction. After pushing the Program Counter onto the stack, the operand specified by JSR is placed into the Program Counter, which effectively transfers control to the subroutine.

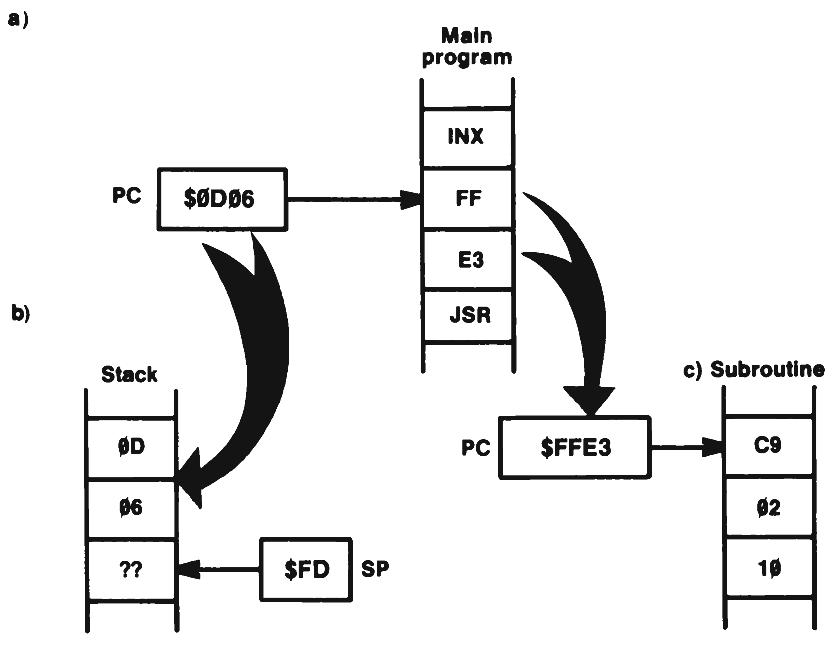


Figure 14.1 Steps taken by a JSR instruction.

Figure 14.1 shows how these operations take place, and in particular, their effect on the stack. At the time the 6510 encounters the JSR instruction the Program Counter is pointing to the second byte of the two byte operand (Figure 14.1a). The microprocessor pushes the contents of the Program Counter onto the stack, low byte first (Figure 14.1b), and then copies the subroutine address into the Program Counter (Figure 14.1c).

When the RTS instruction is encountered at the end of the subroutine, these actions are reversed. The return address is pulled from the stack and incremented by one (Figure 14.2) as it is replaced into the Program Counter, so that it points to the instruction after the original subroutine call.

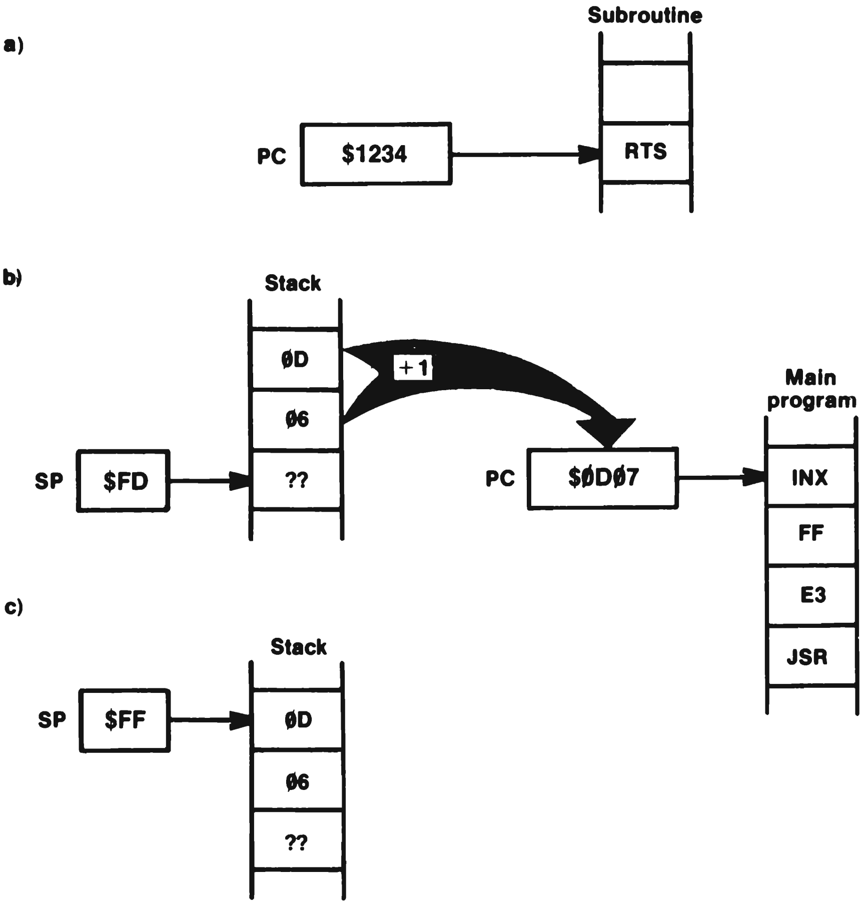


Figure 14.2 Steps taken by an RTS instruction

PASSING PARAMETERS

Nine times out of ten a subroutine will require some data to work on, and this will have to be passed into the subroutine by the main program. For example, in Program 24, the values to be printed were placed into the accumulator before calling the CHROUT routine. This routine is written such that it expects to find a data byte in the accumulator. Other subroutines may require several bytes of information, in which case the accumulator alone would not be sufficient. There are three general ways in which information or parameters can be passed into subroutines, these are:

1. Through registers.
2. Through memory locations.
3. Through the stack.

Let's look at each of these methods in turn.

Through registers

This is quite obviously the simplest method particularly because it can keep the subroutine independent of memory. Because only three registers are available though, only three bytes of information can be conveyed. The registers may themselves contain vital information, so this would need to be saved, possibly on the stack, for future restoration.

Through memory

This is probably the easiest method if numerous bytes are being passed into the subroutine. The most efficient way is to use memory in zero page between locations $FB and $FE inclusive, because this is reserved for user applications. If the subroutine uses several bytes of memory, a neat way of accessing them is to place the start address of the data in the X register, and then use zero page indexed addressing with $00 as the operand as follows:

```
LDX $FB
JSR Subroutine
. . .
                Subroutine  LDA $00, X
                            . . .
                            INX
                            CPX #$FE
                            BNE Subroutine
                            RTS
```

The disadvantage of using memory locations to pass parameters is that it ties the subroutine to a given area, making it memory dependent. However, on most occasions this does not really matter.

Through the stack

Passing parameters through the stack needs care, since the top of the stack will contain the return address. This method also requires two bytes of memory in which the return address can be saved after pulling it from the stack (though, of course, the index registers could be used). If the stack is used, the subroutine needs to commence with:

```
PLA                 \ pull low byte
STA  ADDR           \ and save it
PLA                 \ pull high byte
STA  ADDR + 1       \ and save it
```

The STA instructions can be replaced by TAX and TAY respectively. It is common practice when using the index registers to hold an address, to place the low byte in the X register and the high byte in the Y register.

Once the parameters have been pulled from the stack the return address can be pushed back on to it with,

```
LDA ADDR + 1
PHA
LDA ADDR
PHA
```

Remember, the stack is a LIFO structure, so the bytes need to be accessed and pushed in the reverse order from that in which they were pulled and saved.

If a variable number of parameters is being passed into the subroutine, the actual number can be ascertained each time by evaluating the contents of the Stack Pointer. This can be carried out by transferring its value to the X register with TSX, and incrementing the X register each time the stack is pulled until, say, $FF is reached, indicating the stack is empty. The actual value tested for will depend on whether any other subroutine calls were performed previously—making the current one a nested subroutine. The value $FF is therefore just a hypothetical case and assumes nothing other than that data is present on the stack.

JUMPS

The JMP instruction operates in a similar manner to BASIC's GOTO statement in that it transfers control to another part of the program. In assembler however, an absolute address is specified rather than a line number (which does not, of course, exist in machine code). The instruction operates simply by placing the two byte address specified after the opcode into the Program Counter, effectively producing a jump.

Program 25 creates a continuous loop by jumping back to the start of the program. This is seen as an unending stream of asterisks being printed to the screen—you'll have to press RUN/STOP and RESTORE to get back to BASIC.

Program 25

```
10  REM * * JUMPING * *
20  CODE = 49152
30  FOR LOOP = 0 TO 7
40    READ BYTE
50    POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90                         REM START
100 DATA 169,42            REM $A9, $2A        — LDA #ASC"*"
110 DATA 32,210,255     :  REM $20, $D2, $FF   — JSR $FFD2
120 DATA 76,0,192          REM $4C, $00, $C0   — JMP START
130
140 SYS CODE
```

JMP will generally be used to leapfrog over a section of machine code that need not be executed because a test failed. For example:

```
            BCC OVER
            JMP SOMEWHERE
OVER        LDA BYTE
            ASL A
            INX
            DEY
SOMEWHERE   STA TEMP
```

Here, if the Carry flag is clear, the jump instruction will be skipped and the code of OVER executed. If the Carry flag is set the test will fail, the JMP will be encountered and the code of OVER bypassed.

A further use of JMP, the 'indirect jump', was detailed in Chapter 11. As we saw, the address that is actually jumped to is stored in a vector, the address of which is specified in the instruction. JMP ($FB) being an example.

15 Shifts and Rotates

Basically, these instructions allow the bits in a single byte to be moved one bit to the left or one bit to the right. There are four instructions available:

ASL	Arithmetic shift left
LSR	Logical shift right
ROL	Rotate left
ROR	Rotate right

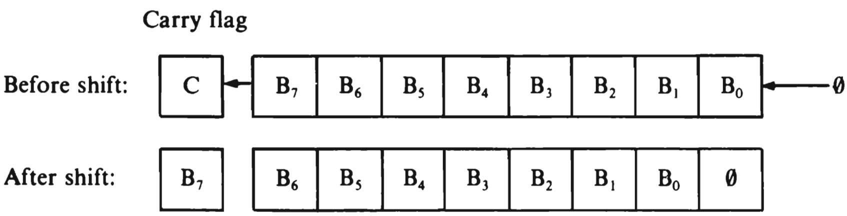
All of these instructions may operate directly on the accumulator, or on a specified memory byte:

```
ASL A          \ arithmetic shift left accumulator
ROL $FB        \ rotate left location $FB
```

Let's investigate each command in more detail.

ARITHMETIC SHIFT LEFT

ASL moves the contents of the specified byte left by a single bit.



Bit 7 (B_7) is shifted into the Carry flag, and a 'Ø' takes the place of bit Ø as the rest of the bits are shuffled left. The overall effect is to double the value of the byte in question.

Example:

			C	Accumulator
LDA $42	\	load accumulator with $42	X	Ø 1 Ø Ø Ø Ø 1 Ø
ASL A	\	shift accumulator left	Ø	1 Ø Ø Ø Ø 1 Ø Ø

The accumulator now holds $84, twice the original value!

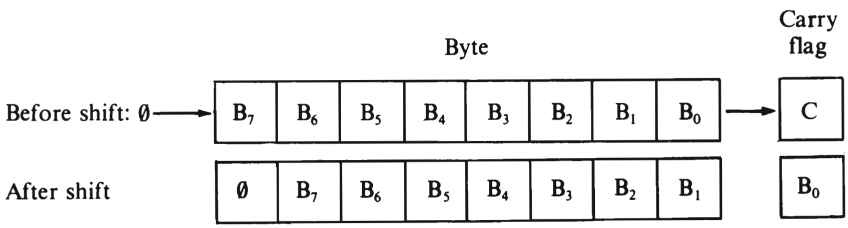
A further example of ASL is given by Program 26 which asks for a number (less than 64), multiplies it by four using ASL A, ASL A, and prints the answer.

Program 26

```
10  REM * * MULTIPLY BY FOUR * *
20  CODE = 49152
30  FOR LOOP = 0 TO 6
40    READ BYTE
50    POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 165,251      REM $A5, $FB   — LDA $FB
100 DATA 10         : REM $0A        — ASL A
110 DATA 10         : REM $0A        — ASL A
120 DATA 133,251      REM $85, $FB   — STA $FB
130 DATA 96         : REM $60        — RTS
140
150 PRINT CHR$ (147)
160 INPUT "NUMBER TO BE MULTIPLIED BY 4"; NUM
170 POKE 251,NUM
180 PRINT "× 4 =";
190 SYS CODE
200 PRINT PEEK(251)
```

LOGICAL SHIFT RIGHT

LSR is similar to ASL except that it moves the bits in the opposite direction, with bit 0 (B_0) jumping into the Carry flag and a 0 following into the spot vacated by bit 7 (B_7).



This instruction could well have been called arithmetic shift right because it effectively divides the byte being shifted by two. For example:

			C	Accumulator
LDA $42	\	load accumulator with $42	X	01000010

		C	
LSR A	\ shift accumulator right	0	00100001

The accumulator now holds $21, half the original value.

Using:

LSR A : BCS Elsewhere

or,

LSR A : BCC Somewhere

is a good efficient way of testing bit 0 of the accumulator.

Program 27 tests the condition of bit 0 of an input ASCII character by shifting it into the **Carry flag position. If the carry is clear a zero is printed, if set—a one is printed instead.**

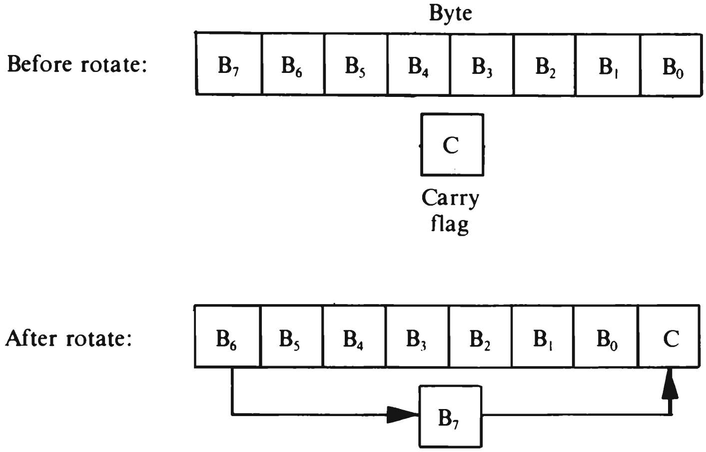
Program 27

```
10  REM * * TEST BIT 0 * *
20  CODE = 49152
30  FOR LOOP = 0 TO 10
40    READ BYTE
50    POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 165,251        REM $A5, $FB        — LDA $FB
100 DATA 74           : REM $4A             — LSR A
110 DATA 169,48         REM $A9, $30        — LDA #ASC"0"
120 DATA 105,0          REM $69, $00        — ADC #0
130 DATA 32,210,255     REM $20, $D2, $FF   — JSR $FFD2
140 DATA 96             REM $60             — RTS
150
160 INPUT A
170 POKE 251, A
180 SYS CODE
```

The input value (line 160) is POKEd into location 251 ($FB). This is then loaded into the accumulator (line 90) and a logical shift right performed (line 100) which moves bit 0 into the Carry flag position—either setting or clearing it. The accumulator is then loaded with the ASCII code value for '0' (line 120) before the ADC instruction adds 0 to it (line 130)! No that's not as crazy as it seems—remember that the ADC instruction takes the value of the Carry flag into consideration. If it is clear then the accumulator will still hold the ASCII code for 0, but if it is set, one will be added to the accumulator's value so that it now holds the ASCII code for 1!

ROTATE LEFT

This instruction uses the Carry flag as a ninth bit, rotating the whole byte left one bit in a circular motion, with bit 7 moving into the Carry flag, which in turn moves across to bit 0.



ROL provides an easy method of testing any of the four bits constituting the upper nibble of the accumulator. The desired bit is rotated into the bit 7 position, thus setting or clearing the Negative flag as appropriate.

Example: test bit 5 of accumulator.

Accumulator	AF	1 0 1 0 1 1 1 1	N = 1
Carry flag	0		

ROL A / rotate bit 6 into the bit 7 position

Accumulator	5E	0 1 0 1 1 1 1 0	N = 0
Carry flag	1		

ROL A / rotate bit 5 into the bit 7 position

Accumulator	BC	1 0 1 1 1 1 0 1	N = 1
Carry flag	0		

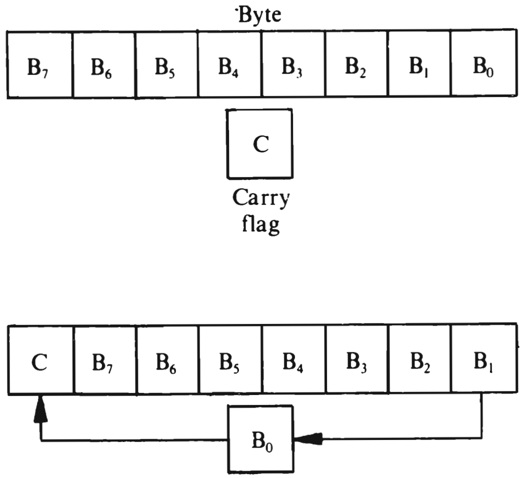
The Negative flag is now set, indicating that bit 5 of the accumulator was set.

ROTATE RIGHT

Works just like ROL except the bits move to the right.

Before rotate:

After rotate:



Example: ROR accumulator containing $8F.

```
CLC         \   clear Carry flag
LDA $8F     \   load accumulator with $8F
```

Accumulator 8F 10001111

Carry flag 0

```
ROR         \   rotate right
```

Accumulator 47 01000111

Carry flag 1

LOGICALLY SPEAKING

If you need to shift (or rotate) the contents of a particular location *several times*, it is more efficient to load the value into the accumulator, shift (or rotate) that and store it back, than to manipulate the location directly.

For example, to rotate location $1234 to the right four times, we could use:

```
ROR $1234
ROR $1234
ROR $1234
ROR $1234
```

This uses twelve bytes of memory, four for the instructions and eight for addresses. Alternatively:

```
LDA $1234
```

```
ROR A
ROR A
ROR A
ROR A
STA $1234
```

uses two bytes less and is 25% quicker in operation.

So far we have only considered shifting and rotating single bytes. By using combinations of instructions it is possible to perform similar operations on two byte values such as $CAFE.

To perform an overall ASL on two bytes located at HIGH and LOW, ASL and ROL are used in conjunction:

```
ASL HIGH        \ shift bit 7 by LOW into Carry flag
ROL LOW         \ rotate it into bit 0 of HIGH
```

By exchanging the commands an overall LSR on the same two bytes can be performed:

```
LSR HIGH        \ shift bit 0 HIGH into Carry flag
ROR LOW         \ rotate it into bit 7 of LOW
```

Note that the bytes are manipulated in the reverse order because we wish to move the bits in the opposite direction. As with single byte shifts, the two byte values can be doubled or divided in half.

Two byte rotates to move the bits in a circular manner, are simply rotation operations performed twice! However, as with two byte shifts, it is important to get the byte rotation order correct.

A two byte ROR is performed with:

```
ROR HIGH        \ rotate bit 0 of HIGH into Carry flag
ROR LOW         \ and on into bit 7 of LOW
```

While two byte ROLs are implemented with:

```
ROL LOW         \ rotate bit 7 of LOW into Carry flag
ROL HIGH        \ and on into bit 0 of HIGH
```

Finally, moving back to single byte shifts, to shift the contents of the accumulator right one bit while preserving the sign bit, use the following technique:

```
TAY             \ save accumulator in Y register
ASL A           \ move sign bit (bit 7) into Carry flag
TYA             \ restore original value back into
                  accumulator
ROR A           \ rotate right moving sign bit back
                  into bit 7
```

The Y register has been used as a temporary store for the accumulator. We could have used the X register or a memory location with equal effect.

PRINTING BINARY!

Quite often, it is necessary to know the binary bit pattern that a register or memory location holds. This is particularly true in the case of the Status register when the condition of its flags can often provide a great deal of information about the way a program is running.

Program 28 shows how the binary value of a byte can be printed. It uses the Status register's contents at the time the program is RUN as an example.

Program 28

```
10  REM * * BINARY OUTPUT OF SR * *
20  CODE = 49152
30  FOR LOOP = 0 TO 18
40     READ BYTE
50     POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 8                REM $08              — PHP
100 DATA 104              REM $68              — PLA
110 DATA 133,251          REM $85, $FB         — STA $FB
120 DATA 162,8            REM $A2, $08         — LDX #$08
130                       REM NBIT
140 DATA 6,251            REM $06, $FB         — ASL $FB
150 DATA 169,48           REM $A9, $30         — LDA #ASC"0"
160 DATA 105,0            REM $69, $00         — ADC #$00
170 DATA 32,210,255  :    REM $20, $D2, $FF    — JSR $FFD2
180 DATA 202              REM $CA              — DEX
190 DATA 208,244          REM $D0, $F4         — BNE NBIT
200 DATA 96               REM $60              — RTS
210
220 PRINT CHR$ (147)
230 PRINT "NV—BDIZC"
240 SYS CODE
```

The Status register needs to be saved in a memory location so that it can be manipulated. To do this it must be transferred into the accumulator by first pushing it on to the stack with PHP (line 90) and then pulling it into the accumulator with PLA (line 100); it can then be stored in zero page at location 251 (line 110). The X register is used to count the eight bits of the byte, so it is initialized accordingly (line 120). Line 130 is used as a label marker for NBIT (short for next bit). The arithmetic shift left (line 140) moves the msb of location 251 ($FB) into the Carry flag. The bit value (0 or 1) is printed out using the ASCII code for 0 and adding the Carry flag contents to it (lines 150 to 170) as described for Program 27. The bit counter is decremented (line 180) and a branch to NBIT executed if X has not reached zero (line 190).

To prove that the program does work, try including lines such as:

```
85  DATA 169,255          REM $A9, $FF         — LDA #$FF set N
85  DATA 169,0            REM $A9, $00         — LDA #$00 clear N set Z
```

These will condition the status flags as indicated. (Don't forget to change the LOOP count in line 3Ø.) You might like to try modifying the program to print the binary value of any key pressed on the keyboard!

BIT

The instruction, BIT, allows individual bits of a specified memory location to be tested. It has an important feature in that it does *not* change the contents of either the accumulator or the memory location being tested, but, as you may have guessed, it conditions various flags within the Status register. Thus:

1. The Negative flag is loaded with the value of bit 7 of the location being tested.
2. The Overflow flag is loaded with the value of bit 6 of the location being tested.
3. The Zero flag is set if the AND operation between the accumulator and the memory location produces a zero.

By loading the accumulator with a mask it is possible to test any particular bit of a memory location. For example, to test location TEMP to see if bit Ø is clear the following could be used:

```
LDA #1            \ ØØØØØØØ1
BIT TEMP          \ test bit Ø
```

If bit Ø of TEMP contains a Ø, the Zero flag will be set, otherwise it will remain clear, thus allowing BNE and BEQ to be used for testing purposes.

This masking procedure need only be used for testing bits Ø to 5 because bits 6 and 7 are automatically copied into the Negative and Overflow flags, which have their own test instructions.

```
BIT TEMP
BMI               \ branch if bit 7 set
BPL               \ branch if bit 7 clear
BVC               \ branch if bit 6 set
BVS               \ branch if bit 6 clear
```

16 Multiplication and Division

MULTIPLICATION

Performing multiplication in assembly language is not too difficult provided that you have grasped what you have read so far. Unfortunately there are no multiplication instructions within the Commodore 64's 6510 instruction set, therefore it is necessary to develop an algorithm to carry out this procedure.

Let's first look at the simplest method of multiplying two small values together. Consider the multiplication 5 × 6. We know the result is 30, but how did we obtain this? Simply by adding together six lots of five, in other words: 5 + 5 + 5 + 5 + 5 + 5 = 30 This is quite easy to implement:

Program 29

```
 10 REM * * SIMPLE MULTIPLICATION * *
 20 CODE = 49152
 30 FOR LOOP = 0 TO 16
 40   READ BYTE
 50   POKE CODE + LOOP, BYTE
 60 NEXT LOOP
 70
 80 REM * * M/C DATA * *
 90 DATA 169,0        REM $A9, $00     — LDA #$00
100 DATA 133,251      REM $85, $FB     — STA $FB
110 DATA 162,6        REM $A2, $06     — LDX #$06
120 DATA 24           REM $18          — CLC
130                   REM LOOP
140 DATA 165,251      REM $A5, $FB     — LDA $FB
150 DATA 105,5        REM $69, $05     — ADC #$05
160 DATA 133,251      REM $85, $FB     — STA $FB
170 DATA 202          REM $CA          — DEX
180 DATA 208,247      REM $D0, $F7     — BNE LOOP
190 DATA 96           REM $60          — RTS
```

```
200
210 SYS CODE
220 PRINT "RESULT = "
230 PRINT PEEK(251)
```

All we have done here is to create a loop to add 5 to the contents of location $FB six times to produce the desired result! This method is reasonable for multiplying small values, but not particularly efficient for larger numbers.

At this point, it might be worth reviewing the usual procedure for multiplying two large decimal numbers together. Consider 123 × 150. We would approach this, (without calculators, please!) thus:

```
  123    (Multiplicand)
 ×150    (Multiplier)
 ----
  000    (Partial product 1)
 615     (Partial product 2)
123      (Partial product 3)
-----
18450    (Result or final product.)
```

The initial two values are termed the multiplicand and multiplier, and their product is formed by multiplying, in turn, each digit in the multiplier by the multiplicand. This results in a partial product, which is written such that its least significant digit sits directly below the multiplier digit to which it corresponds. When formation of all the partial products is completed, they are added together to give the final product or result.

We can apply this technique to binary numbers, starting off with two three bit values, 010 × 011

```
  010    (Multiplicand)
 ×011    (Multiplier)
 ----
  010    (Partial product 1)
 010     (Partial product 2)
000      (Partial product 3)
-----
00110    (Result)
```

Ignoring leading zeros, we obtain the result 110 (2 × 3 = 6). Moving on to our original decimal example, its binary equivalent is:

```
       01111011    123($7B)
      ×10010110    150($96)
      ---------
       00000000
      01111011
     01111011
    00000000
   01111011
  000000000
 00000000
01111011
---------------
100100000010010    18450($4812)
```

Hopefully you will have noticed that if the multiplier digit is a 0 it will result in the whole partial product being a line of zeros (anything multiplied by zero is zero). Therefore if a 0 is present in the multiplier it can simply be ignored *but* we must remember to shift the next partial product up past any 0s so that its least significant digit still corresponds to the correct 1 of the multiplier. This technique of shifting and ignoring can be used to write an efficient multiplication program.

Program 30

```
10  REM * * SINGLE BYTE MULT GIVING 2 BYTE RESULT * *
20  CODE = 49152
30  FOR LOOP = 0 TO 19
40     READ BYTE
50     POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 162,8        REM $A2, $08     — LDX #$08
100 DATA 169,0        REM $A9, $00     — LDA #$00
110                   REM AGAIN
120 DATA 70,252       REM $46, $FC     — LSR $FC
130 DATA 144,3        REM $90, $03     — BCC OVER
140 DATA 24           REM $18          — CLC
150 DATA 101,251      REM $65, $FB     — ADC $FB
160                   REM OVER
170 DATA 106          REM $6A          — ROR A
180 DATA 102,253      REM $66, $FD     — ROR $FD
190 DATA 202          REM $CA          — DEX
200 DATA 208,243      REM $D0, $F3     — BNE AGAIN
210 DATA 133,254      REM $85, $FE     — STA $FE
220 DATA 96           REM $60          — RTS
230
240 PRINT CHR$(147)
250 INPUT "MULTIPLICAND"; A
260 INPUT "MULTIPLIER"; B
270 POKE 251, A : POKE 252, B
280 SYS CODE
290 HIGH = PEEK(254) : LOW = PEEK(253)
300 RESULT = HIGH * 256 + LOW
310 PRINT "RESULT IS ";
320 PRINT RESULT
```

This program takes two single byte numbers, multiplies them together storing the result (which may be 16 bits long) in zero page. Unlike the binary multiplication examples, it does not compute each partial product before adding them together, but totals the partial products as they are evaluated. This is a somewhat quicker method, because the final product is generated as soon as the last bit of the multiplier has been examined.

When RUN the program requests you to enter the multiplicand and multiplier (lines 250 and 260); these single byte values are then POKEd into memory. The machine code begins by setting the X register to 8 ready to act as the bit counter (line 90). The accumulator is then cleared—this is important as it affects the high result value in location 254 ($FE). The main loop is marked by the label in line 110. Bit 0 of the multiplier is then shifted into the Carry flag (line 120) and a branch to OVER executed if the Carry is clear (line 140). If set, the multiplicand value needs to be added to the accumulator (line 150). The product value now in the accumulator is rotated right (line 170) and a further ROR on the low result byte at 253 ($FD) performed (line 180). These two operations move bit 0 of the accumulator into bit 7 of the low result byte. The X register is decremented (line 190) and the procedure repeated for bits 1–7.

As may have become clear in the last binary example, the procedure is—*if* the bit is set *then* add the byte, *else* ignore it and move on to the next shifting operation.

DIVISION

When performing the division of one number by another, we are actually calculating the number of times the second number can be subtracted from the first. Consider 125 ÷ 5:

```
                 25    (Quotient)
(Divisor)      5|125   (Dividend)
               -10
                ---
                 25
                 25
                 --
                  0    (Remainder)
```

Here, 5 can be subtracted from 10 twice, so we note the value 2 as part of the quotient. The 10 is brought down and subtracted from the first two digits of the dividend, leaving 2. Because 5 cannot be subtracted from 2 the remaining 5 of the dividend is brought down to give 25. 5 can be subtracted from this, without remainder, 5 times. Again this is recorded in the quotient, which now reflects the final result.

To divide binary numbers, this same procedure is pursued. The above example in binary would look like this:

```
          00011001
     0101|01111101
          0101
          ----
            10
          ----
            101
            101
            ---
              0
            ---
              101
              101
              ---
                0
```

In fact, as you may see, dividing binary numbers is much simpler than dividing decimal numbers. If the divisor is less than or equal to the dividend the corresponding bit in the quotient will be a 1. If the subtraction is not possible a 0 is placed in the quotient, the next bit of the dividend is brought down, and the procedure repeated.

The following utility program divides two single byte values and indicates whether a remainder is present:

Program 31

```
10  REM * * SINGLE BYTE DIVIDE * *
20  CODE = 49152
30  FOR LOOP = 0 TO 20
40     READ BYTE
```

```
50   POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 162,8           REM $A2, $08        — LDX #$08
100 DATA 169,0           REM $A9, $00        — LDA #$00
110                      REM AGAIN
120 DATA 6,251           REM $06, $FB        — ASL $FB
130 DATA 42              REM $2A             — ROL A
140 DATA 197,252         REM $C5, $FC        — CMP $FC
150 DATA 144,4           REM $90, $04        — BCC OVER
160 DATA 229, 252        REM $E5, $FC        — SBC $FC
170 DATA 230,251         REM $E6, $FB        — INC $FB
180                      REM OVER
190 DATA 202             REM $CA             — DEX
200 DATA 208,242         REM $D0, $F2        — BNE AGAIN
210 DATA 133,253         REM $85, $FD        — STA $FD
220 DATA 96              REM $60             — RTS
230
240 PRINT
250 INPUT "DIVIDEND"; A
260 INPUT "DIVISOR"; B
270 POKE 251,A : POKE 252,B
280 SYS CODE
290 PRINT "RESULT = ";
300 PRINT PEEK(251)
310 PRINT "REMAINDER = ";
320 PRINT PEEK(253)
```

In case you cannot readily follow what the program is doing, here is a line by line description of the mnemonics:

Line 90	Initialize the X register to indicate the number of bits to be shifted—1 byte = 8 bits.
Line 100	Clear accumulator which will hold partial dividend value.
Line 110	Set loop.
Line 120	Shift the dividend left to provide the least significant bit position for the next digit of the quotient.
Line 130	The dividend bit is shifted left so that another bit from the partial dividend (which is in accumulator) can be tested.
Line 140	The divisor and partial dividend are compared.
Line 150	If the result indicates that the divisor is less than, or equal to the partial dividend . . .
Line 160	. . . the divisor is subtracted from the partial dividend . . .
Line 170	. . . and a 1 added to the quotient.
Line 180	If compare shows that the divisor is greater than the partial dividend, these last two lines are skipped.

Line 190 The bit count is decremented . . .
Line 200 . . . and control returned to line 110 if not complete.
Line 210 Any remainder is saved in $FD.

This program uses the shift instructions of lines 120 and 130 as a two byte shift register in which the accumulator acts as the higher byte. The carry produced by ROL A is insignificant, in fact it is 0, and is eroded by the next ASL $FB procedure.

17 Assembly Types

CONDITIONAL ASSEMBLY

Conditional assembly allows different parts of an assembly language program to be assembled in response to certain different conditions being met. One of its main advantages is that a general source file can be created, rather than developing different source files for each particular need. The relevant code can be selected in response to a menu, or simply by seeding variable parameters.

Program 32 contains two different routines (multibyte addition and multibyte subtraction), but, depending on the response to the menu selection, only one of them will be assembled.

Program 32

```
10  REM * * CONDITIONAL ASSEMBLY * *
20  CODE = 49152
30  PRINT CHR$(147)
40  PRINT SPC(8)
50  PRINT "CONDITIONAL ASSEMBLY"
60  PRINT "PRESS 1 TO ASSEMBLE MBADD"
70  PRINT "       2 TO ASSEMBLE MBSUB"
80  GET A$
90  A = VAL(A$)
100 IF A = 1 THEN GOTO 200
110 IF A = 2 THEN GOTO 300
120 GOTO 80
130
190 REM * * ASSEMBLE MBADD * *
200 RESTORE
210 FOR LOOP = 0 TO 18
220   READ BYTE
230   POKE CODE + LOOP, BYTE
240 NEXT LOOP
250 END
```

```
260
290  REM * *ASSEMBLE MBSUB * *
300  RESTORE
310  READ BYTE
320  IF BYTE <> 96 THEN GOTO 310
330  GOTO 210
340
350  REM * * MBADD DATA * *
360  DATA 164,251          REM $A4, $FB          — LDY $FB
370  DATA 162,0            REM $A2, $00          — LDX #$00
380  DATA 24               REM $18               — CLC
390                        REM AGAIN
400  DATA 189,0,21         REM $BD, $00, $15     — LDA $1500,X
410  DATA 125,0,22       : REM $7D, $00, $16     — ADC $1600,X
420  DATA 157,0,21         REM $9D, $00, $15     — STA $1500,X
430  DATA 232              REM $E8               — INX
440  DATA 136            : REM $88               — DEY
450  DATA 208,243          REM $D0, $F3          — BNE AGAIN
460  DATA 96               REM $60               — RTS
470
480  REM * * MBSUB DATA * *
490  DATA 164,251          REM $A4, $FB          — LDA $FB
500  DATA 162,0          : REM $A2, $00          — LDX #$00
510  DATA 56             : REM $38               — SEC
520                        REM AGAIN
530  DATA 189,0,23         REM $BD, $00, $17     — LDA $1700,X
540  DATA 253,0,24       : REM $FD, $00, $18     — SBC $1800,X
550  DATA 157,0,23         REM $9D, $00, $17     — STA $1700,X
560  DATA 232              REM $E8               — INX
570  DATA 136              REM $88               — DEY
580  DATA 208,243          REM $D0, $F3          — BNE AGAIN
590  DATA 96               REM $60               — RTS
```

If item 1 is selected from the menu then the machine code is read and assembled in the normal manner by the BASIC loop of lines 210 to 240. If item 2 is selected we need to move the DATA pointer on so that it points to the first data byte in the MBSUB data listing. To do this a dummy READing loop is initiated in lines 310–320. This loop keeps reading bytes until BYTE = 96. This marks the end of the MBADD routine as 96 is of course the opcode for the RTS instruction. Now that the DATA pointer is in the correct position line 330 loops back for the machine code of MBSUB to be assembled in the normal manner.

MBADD uses absolute indexed addressing to sequentially fetch a byte of one operand (line 400) and add it to the corresponding byte of the other operand (line 410). The result is then stored in the location of the first operand. The Y register, having previously been loaded with the number of addition bytes via the zero page location 251 ($FB), is decremented (line 440), and the operation is continued until the Y register value has been exhuasted. The two multibyte numbers for addition should, of course, be stored in memory from locations $1500 and $1600 respectively.

The second routine, lines 490 to 590, is a multibyte subtraction routine (MBSUB) and is assembled by selecting item 2 on the menu. MBSUB also uses absolute indexed addressing to subtract the multibyte number at $1800 onwards from a similar number at $1700 onwards. Again the byte length of the number is stored in 251 ($FB).

LOOK-UP TABLES

Look-up tables provide a neat, compact and efficient way of obtaining data for what might otherwise turn out to be long and complicated machine code programs. For example, suppose we want to develop a machine code program to convert degrees Centigrade into degrees Fahrenheit. The formula for this is:

$$°F = 1.8\ (°C) + 32$$

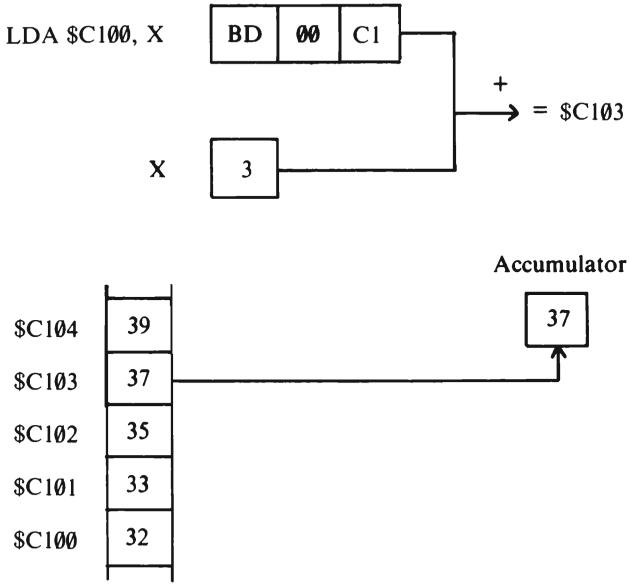
As you can see, this requires two mathematical operations—first a multiplication then an addition (a bit painful to the grey matter!). By providing the conversion values precalculated in a table, the Fahrenheit values can be extracted by using the Centigrade value as in *index* to the table. Try the following program:

Program 35

```
10  REM * * CENTIGRADE TO FAHRENHEIT * *
20  CODE = 49152
30  FOR LOOP = 0 TO 7
40    READ BYTE
50    POKE CODE + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 166,251      REM $A6, $FB       — LDX $FB
100 DATA 189,0,193    REM $BD, $00, $C1  — LDA $C100,X
110 DATA 133,252      REM $85, $FC       — STA $FC
120 DATA 96           REM $60            — RTS
130
140 REM * * CALCULATE TABLE VALUES * *
150 FOR C=0 TO 100
160   F = (1.8 * C) + 32
170   POKE 49408 + C, F
180 NEXT C
190
200 PRINT CHR$(147)
210 INPUT "CENTIGRADE VALUE"; C
220 POKE 251, C
230 SYS CODE
240 PRINT "FAHRENHEIT VALUE";
250 PRINT PEEK(252)
```

Lines 150 to 180 calculate the equivalent Fahrenheit values for Centigrade values in the range 0–100. Each value is POKEd in turn into memory, to form a table which has its base at 49408 ($C100). The input Centigrade value for conversion is POKEd into location 251 ($FB), and subsequently loaded into the X register when the machine code is executed (line 90). This value is used as the index to the table when loading the accumulator with the corresponding Fahrenheit value (line 100). This Fahrenheit value is stored in location 252 ($FC) so that it can be accessed by the calling BASIC. The following example illustrates this graphically.

Example: Convert 3°C to Fahrenheit.



Therefore 3°C is equivalent to 37°F.

18 Sprite of 64

For my money, the most endearing aspect of the Commodore 64 is the ease with which sprite graphics can be produced and controlled. This is so easy, in fact, that it is almost as simple to produce them from machine code programs as it is from BASIC!

The Commodore 64 has a special chip, the Versatile Interface Chip (VIC), through which up to eight sprites can be controlled at any one time. The VIC is a *memory-mapped device*—this means that it actually appears as part of the Commodore's memory map—in fact, it occupies 46 locations from 53248 to 54271 ($DØØØ–$DØ2E). These locations are generally referred to as the 'registers' of the VIC, because various events and effects are controlled by POKEing predetermined values into them. Table 18.1 details the function of each register. If you have used sprites from BASIC before you will be quite familiar with this. From machine code, all we need to do is to POKE the locations by first loading the relevant value into the accumulator (or one of the index registers) and then storing it in the relevant VIC register.

Because incorrectly written machine code can cause your micro to hang-up, it's not a bad idea to create the sprite and effect you want in BASIC, and only when you are satisfied with it to translate it into machine code—in fact, this is the approach most software houses use! As an example, let's see if we can get the USS Enterprise to fly across the screen "... where no man has gone before . . ." under full machine code control!

First we need to define the shape—this can be done using one of the Sprite Definition Charts given in either the *User Guide* or *Programmers Reference Guide.* Figure 18.1 shows how my attempt turned out. The grid is divided horizontally into 3 main columns, each of which is subdivided into a further 8 columns. Each 'major' column represents one byte and the minor colums bits within the byte. We need to convert each row of bytes into the decimal number derived from the 'bit pattern' of the byte.

We saw how to convert between bases in Chapter 2, but just to jog your memory, what we need to do is to work across the byte and *add the weight* for each bit that is set (coloured in). Clear bits have weight Ø. For example, from Figure 18.1 we can see that the first three bytes across the top are all clear, thus the values of these bytes are Ø, Ø and Ø respectively. Moving on to the second row, the first byte has all bits set except the most significant, therefore its value is:

```
Ø   1   1   1   1   1   1   1
    64+32+16  +8  +4  +2  +1= 127
```

Similarly, the second byte has all bits set except the least significant, therefore its binary value is:

```
1    1   1   1   1   1   1   Ø
128+ 64+ 32+ 16  +8  +4  +2  +Ø= 254
```

Table 18.1 VIC registers

Address		Function
Decimal	Hex	
53248	D000	Sprite 0 X coordinate
53249	D001	Sprite 0 Y coordinate
53250	D002	Sprite 1 X coordinate
53251	D003	Sprite 1 Y coordinate
53252	D004	Sprite 2 X coordinate
53253	D005	Sprite 2 Y coordinate
53254	D006	Sprite 3 X coordinate
53255	D007	Sprite 3 Y coordinate
53256	D008	Sprite 4 X coordinate
53257	D009	Sprite 4 Y coordinate
53258	D00A	Sprite 5 X coordinate
53259	D00B	Sprite 5 Y coordinate
53260	D00C	Sprite 6 X coordinate
53261	D00D	Sprite 6 Y coordinate
53262	D00E	Sprite 7 X coordinate
53263	D00F	Sprite 7 Y coordinate
53264	D010	Sprites 0–7 most significant bit of X coordinate
53265	D011	VIC control register
53266	D012	Raster latch
53267	D013	Light pen latch X coordinate
53268	D014	Light pen latch Y coordinate
53269	D015	Sprite enable (1 = enable)
53270	D016	VIC control register
		7, 6 unused
		5 always 0
		4 multicoloured mode if set
		3 select 38/40 column text (0 = 38, 1 = 40)
		2, 1, 0, X position scroll
53271	D017	Sprites 0–7 vertical expansion
53272	D018	VIC memory control register
53273	D019	VIC interrupt flag register
53274	D01A	VIC IRQ enable register
53275	D01B	Sprite–background display priority (1 = sprite)
53276	D01C	Sprites 0–7 multicolour mode select
53277	D01D	Sprites 0–7 horizontal expansion
53278	D01E	Sprite–sprite collision register
53279	D01F	Sprite–background collision register
53280	D020	Border colour
53281	D021	Background colour 0
53282	D022	Background colour 1
53283	D023	Background colour 2
53284	D024	Background colour 3
53285	D025	Sprite multicolour register 0
53286	D026	Sprite multicolour register 1
53287	D027	Sprite 0 colour
53288	D028	Sprite 1 colour
53289	D029	Sprite 2 colour
53290	D02A	Sprite 3 colour
53291	D02B	Sprite 4 colour
53292	D02C	Sprite 5 colour
53293	D02D	Sprite 6 colour
53294	D02E	Sprite 7 colour

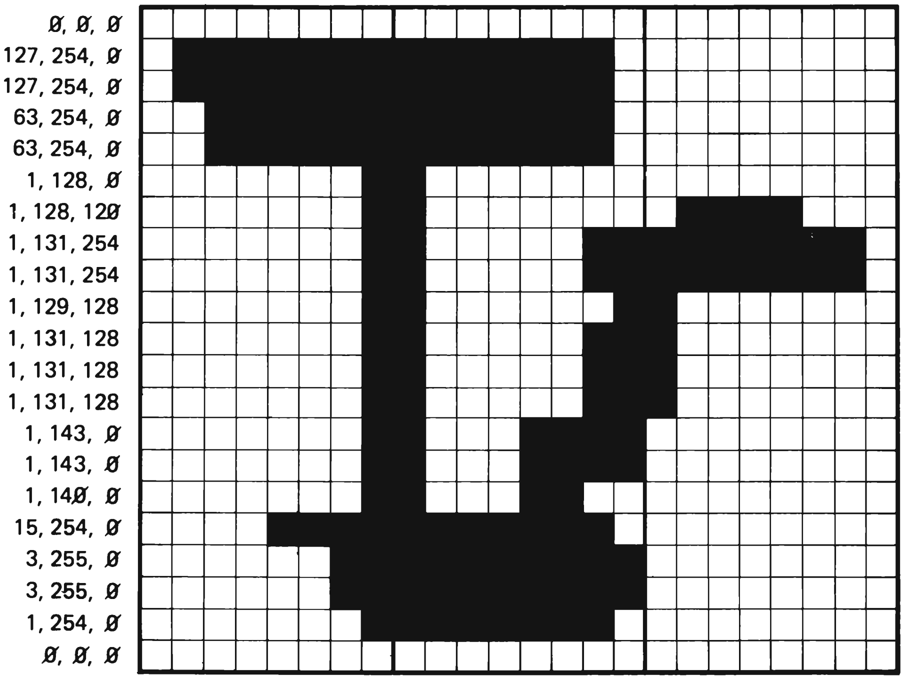


Figure 18.1 The USS Enterprise.

The third byte in the second row is clear and is therefore equal to Ø. This process is continued until all 63 bytes on the chart have had their decimal value calculated from their bit pattern. The results are included down the side of Figure 18.1.

The bit patterns (in decimal form) can now be included into DATA statements as follows:

Program 36a

```
1ØØ  FOR N = Ø TO 62
11Ø    READ BYTE
12Ø    POKE 832 + N, BYTE
13Ø  NEXT
2ØØ  DATA Ø,Ø,Ø
2Ø1  DATA 127,254,Ø
2Ø2  DATA 127,254,Ø
2Ø3  DATA 63,254,Ø
2Ø4  DATA 63,254,Ø
2Ø5  DATA 1,128,Ø
2Ø6  DATA 1,128,12Ø
2Ø7  DATA 1,131,254
2Ø8  DATA 1,131,254
2Ø9  DATA 1,129,128
21Ø  DATA 1,131,128
211  DATA 1,131,128
```

```
212 DATA 1,131,128
213 DATA 1,143,0
214 DATA 1,143,0
215 DATA 1,140,0
216 DATA 15,254,0
217 DATA 3,255,0
218 DATA 3,255,0
219 DATA 1,254,0
220 DATA 0,0,0
```

The FOR . . . NEXT loop (lines 100–130) is responsible for READing each DATA item and POKEing it into memory. This section of program will remain the same for both machine code and BASIC so if you are following this example through it is a very good idea to save it on tape. To inform the VIC where the sprite DATA is stored, it is necessary to program the corresponding *sprite pointer.* These are located in the last 8 bytes of the screen memory, starting with Sprite 0 at 2040 ($07F8) and ending with Sprite 7 at 2047 ($07FF). As each sprite pointer is a single byte it can hold any number in the range 0 to 255. Obviously, this is not enough to hold an address, so instead the value chosen just points to a memory block. As each sprite definition uses 64 bytes (63 for DATA plus one for a marker) it is possible to store sprites anywhere in the first 16K of RAM (because 64 * 256 = 16K). In Program 36a the DATA was written into the tape input/output buffer from location 832 onwards. The pointer value for this is 13, because 13 * 64 = 832, so this value should be POKEd into the sprite pointer.

We can define our Enterprise as any sprite—let's use Sprite 2. To initialize the pointer in the program use:

```
POKE 2042, 13
```

Sprite 7	Bit 7	Msb
Sprite 6	Bit 6	
Sprite 5	Bit 5	
Sprite 4	Bit 4	
Sprite 3	Bit 3	
Sprite 2	Bit 2	
Sprite 1	Bit 1	
Sprite 0	Bit 0	Lsb

Figure 18.2 The sprite enable register at location 53269 ($D015).

To display the sprite on the screen it has to be 'turned-on' by writing to the *sprite enable register* at 53269; Figure 18.2 shows how this register is organized. Each bit is associated with a particular sprite—turning sprites on and off is accomplished by setting and clearing the relative bits. Thus, to switch on Sprite 2, bit 2 of the enable register must be set. In binary this is represented by:

00000100 = 4

Therefore, Sprite 2 is enabled using:

```
POKE 53269,4
```

To prevent the Enterprise looking a bit squashed we can 'expand' it horizontally by writing to bit 2 of the *horizontal expansion register* at 53277:

```
POKE 53277,4
```

Finally the sprite must be positioned on the screen and (suprise, suprise!) there are two registers associated with the X and Y axes (at 53252 and 53253 respectively). To position it somewhere near the centre of the screen use:

```
POKE 53252,130 : POKE 53253,130
```

The next bit of the sprite program looks like this in BASIC:

```
10  PRINT CHR$(147)
20  POKE 2042,13        REM data in block 13
30  POKE 53269,4        REM enable Sprite 2
40  POKE 53277,4        REM expand in X direction
50  POKE 53252,130      REM X coordinate
60  POKE 53253,130      REM Y coordinate
```

Remember to add lines 100 to 220 from Program 36a and then RUN. A USS Enterprise should now be sitting roughly in the middle of your TV screen!

You can now see just how easy it is going to be to program the VIC in machine code because POKE has a direct equivalent in assembler:

```
LDA #value
STA register
```

So, we can rewrite the six lines above thus:

Program 36b

```
10  CODE = 49152
20  FOR LOOP = 0 TO 26
25    READ BYTE
30    POKE CODE + LOOP, BYTE
35  NEXT LOOP
40  REM * * M/C DATA FOR SPRITE CONTROL * *
42  DATA 169,147          REM $A9, $93          — LDA #$93
44  DATA 32,210,255   :   REM $20, $D2, $FF     — JSR PRINT
46  DATA 169,13           REM $A9, $0D          — LDA #13
48  DATA 141,250,7        REM $8D, $FA, $07     — STA 2042
50  DATA 169,4            REM $A9, $04          — LDA #4
52  DATA 141,21,208       REM $8D, $15, $D0     — STA 53269
54  DATA 141,29,208       REM $8D, $1D, $D0     — STA 53277
56  DATA 169,130          REM $A9, $82          — LDA #130
58  DATA 141,4,208        REM $8D, $04, $D0     — STA 53252
60  DATA 141,5,208        REM $8D, $05, $D0     — STA 53253
70  DATA 96               REM $60               — RTS
```

Once again, don't forget to add the original DATA statements from Program 36a. When RUN, each byte will be assembled into the 'free' RAM area and the sprite should appear when SYS CODE is executed. Simple!

MOVING SPRITES

To create the illusion of movement we need only to gradually alter the X or Y coordinate register. In BASIC, we can 'fly' the Enterprise across the screen by placing the X coordinate register inside a FOR . . . NEXT loop. The revised BASIC-only version becomes:

```
10  PRINT CHR$(147)
20  POKE 2042, 13
30  POKE 53269, 4
40  POKE 53277, 4
50  POKE 53253, 100 : REM set height on screen
55  FOR N = 0 TO 255
60    POKE 53252, N : REM increment X
65  NEXT N
70  REM   add Program 36a here
```

Now, the X coordinate register is incremented from 0 to 255. Each time round the loop the location 53253 is POKEd with a new X value thereby repositioning the sprite. Once again, the loop could be written in machine code—but because the machine code is executed so quickly, our eyes wouldn't be able to see the movement. We need to slow it down somewhat. Chapter 21 explains how delay loops can be implemented, but for now we'll use a different technique.

Program 36c

```
 5  REM * * THE ENTERPRISE FLIES * *
10  CODE = 49152
20  FOR LOOP = 0 TO 41
25     READ BYTE
30     POKE CODE + LOOP, BYTE
35  NEXT LOOP
40  REM * * M/C DATA FOR FINAL SPRITE * *
42  DATA 169,147        REM $A9, $93        — LDA #$93
44  DATA 32,210,255     REM $20, $D2, $FF   — JSR $FFD2
46  DATA 169,13         REM $A9, $0D        — LDA #13
48  DATA 141,250,7    : REM $8D, $FA, $07   — STA 2042
50  DATA 169,4          REM $A9, $04        — LDA #4
52  DATA 141,21,208     REM $8D, $15, $D0   — STA 53269
54  DATA 141,29,208     REM $8D, $1D, $D0   — STA 53277
56  DATA 169,100      : REM $A9, $64        — LDA #100
58  DATA 141,5,208      REM $8D, $05, $D0   — STA 53253
60  DATA 162,0          REM $A2,$00         — LDX #00
62                      REM AGAIN
```

```
64   DATA 138              REM $8A              — TXA
66   DATA 141,4,208        REM $8D, $04, $D0    — STA 53252
68   DATA 134,251          REM $86, $FB         — STX $FB
70                         REM WAIT
72   DATA 32,228,255       REM $20, $E4, $FF    — JSR $FFE4
74   DATA 240,251          REM $F0, $FB         — BEQ WAIT
76   DATA 166,251          REM $A6, $FB         — LDX $FB
78   DATA 232              REM $E8              — INX
80   DATA 208,240          REM $D0, $F0         — BNE AGAIN
82   DATA 96             : REM $60              — RTS
90   REM add Program 36a here
230  SYS CODE
```

The machine code loop is set up between lines 62 and 78 with the X register being used as the counter. Each time round its value is transferred to the accumulator and stored in the appropriate VIC register. The loop is delayed by a call to the Kernal GETIN routine at $FFE4, and it only continues when a keypress is detected (lines 72 and 74). This Kernal routine is described in the next chapter—note though, that our value for X must be saved before the Kernal call, because the GETIN subroutine also uses the X register. (Our value for X is restored after a keypress has been detected.)

When you run this program you will find, as with the last BASIC version, that the sprite does not travel fully across the screen but stops about two-thirds of the way across. This is because there are more than 255 X coordinate positions across the screen—in fact there are 65 more! The reason that we cannot continue is, of course, because 255 is the maximum value of a single byte. To enable us to write the sprite on this remaining part of the screen there is a further register at 53264. By setting the corresponding sprite bit in *this* register and then incrementing the X coordinate register as before, our sprite will continue its journey across the screen. This can be done by adding the following lines to our BASIC-only program:

```
70  POKE 53264, 4 : REM enable Sprite 2 in far screen
72  FOR X = 0 TO 100
74    POKE 53252, X
76  NEXT X
```

Once again, this can easily be translated into machine code—but I'll leave that up to you this time! By the way, to write to the normal area of the screen you'll need to un-POKE location 53264 to disable the register using:

```
POKE 53264, 0
```

19 Floating a Point

So far throughout this introduction to assembly language programming we have only been concerned with *integers*, or whole numbers. As in the real world though, *floating point* numbers also exist in the machine code world. A floating point number is one that contains a decimal point (although in binary this is more correctly referred to as a 'bicimal' point).

For example, the denary number 5.25 is a floating point number whereas the number 7 is a whole or integer number. In CBM BASIC the binary floating point numbers have what is known as 10 digit precision, displayed with 9 digits and with exponents in the range +37 to −38. The exponent of a number is simply a scientific notational form of representing numbers. For example, the number 1234.567 could be expressed exponentially as:

0.1234567E+4

The 'E' denotes the exponential value and the +4 the fact that the decimal point has been moved four places in a positive direction. Another way of writing this exponentially is:

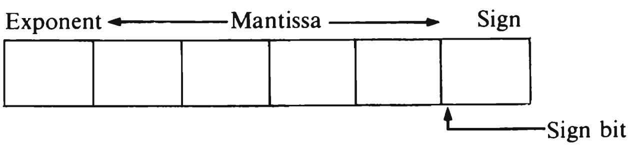
0.1234567×10^4

Similarly, the decimal value 0.0000123 can be expressed as 0.123E–4 or 0.123×10^{-4}, the −4 indicating that the decimal point has been moved four places in a negative direction.

THE FLOATING POINT ACCUMULATORS

The 6510 is provided with two memory-mapped floating point accumulators which manipulate the floating point numbers. These are known as the FAC (Floating Point Accumulator) and the AFAC (Alternative Floating Point Accumulator)—also known as FAC#1 and FAC#2. The addresses associated with them in zero page are shown in Table 19.1 overpage.

Looking at the two floating point accumulators we can see that each has six associated bytes. As already mentioned, each value has 10 digit precision, so to enable the value to be packed into six bytes it must be broken down into two components called the *binary mantissa* and the *binary exponent*. These are illustrated in Figure 19.1.



FAC	97	98	99	100	101	102
AFAC	105	106	107	108	109	110

Figure 19.1 Floating point accumulator architecture.

Table 19.1

Label	Address		Description
	Decimal	Hex	
FACEXP	97	$ØØ61	FAC#1 exponent
FACHO	98–1Ø1	$ØØ62–$ØØ65	FAC#1 mantissa
FACSGN	1Ø2	$ØØ67	FAC#1 sign
BITS	1Ø4	$ØØ68	FAC#1 overflow digit
ARGEXP	1Ø5	$ØØ69	FAC#2 exponent
ARGHO	1Ø6–1Ø9	$ØØ6A–$ØØ6D	FAC#2 mantissa
ARGSGN	11Ø	$ØØ6E	FAC#2 sign
ARIGN	111	$ØØ6F	Sign comparison result FAC#1 v FAC#2

The binary mantissa is the 'number' part of the value, and this is stored in the centre four bytes of the FAC (and AFAC). The sign of the number denotes whether it is a positive or negative value, and this is stored in the sixth byte of the FAC (or AFAC). Only a single bit (bit 7) is required to store the sign—'1' represents a negative mantissa and 'Ø' a positive mantissa.

The binary exponent is the first byte of the FAC (and AFAC) and this is used to represent both positive and negative exponent values by adding the value to, or subtracting the value from, 128. For example, an exponent of +15 is represented by:

+15 = 128 + 15 = 143

Whereas a negative exponent of −15 is expressed as:

−15 = 128 − 15 = 113

To allow a variety of floating point numbers to be handled by a standard set of floating point subroutines, the Commodore 64's BASIC Interpreter *normalizes* them to a representation such that the most significant bit is *always* a '1'.

Consider the hexadecimal number $Ø345. Writing this in binary form we obtain:

$Ø345 = ØØØØ ØØ11 Ø1ØØ Ø1Ø1

In this case, the binary now has an exponent value of 2, or more correctly 1↑2 with the bicimal point being at the far right of the number. If we were to express this properly in exponential form we would read:

ØØØØ ØØ11 Ø1ØØ Ø1Ø1 × 2↑Ø

Now, to normalize this value we need to 'float' the bicimal point along to the left until it sits in front of the leftmost '1'. Figure 19.2 shows the process. Now, if we count the number of shifts we obtain our exponent value, which in this case is 1Ø. Thus:

$Ø345 = Ø.11Ø1 ØØØ1 Ø1ØØ ØØØØ × 2↑1Ø

To represent this in either of the floating point accumulators we must add the exponential value to 128 giving an exponent value of:

128 + 1Ø = 138 = $8A   (1ØØØ 1Ø1Ø)

Figure 19.2 Floating the bicimal point.

Moving back to the mantissa, we have four bytes to fill, therefore the least significant bits must be padded out with 0s to give:

1101 0001   0100 0000   0000 0000   0000 0000

Finally, to complete our normalization of $0345 we must indicate a positive value by placing a 0 in bit 7 of the sign byte. Our final representation of $0345 is given by:

Exponent	1st byte	1000	1010	$8A	
Mantissa	2nd byte	1101	0001	$D1	
	3rd byte	0100	0000	$40	
	4th byte	0000	0000	$00	(padded bytes)
	5th byte	0000	0000	$00	
Sign	6th byte	0xxx	xxxx		

The xs in the sign byte denote that these bits may have any value.

The example given above was really an integer one, but numbers that do contain bicimal values can be normalized in exactly the same manner. For instance, the decimal value 255.75 can be expressed in binary terms as:

1111 1111 . 11

This can be normalized as before, giving a binary exponential representation of:

.1111 1111 1100 0000 × 2↑8

USING USR

A further BASIC statement, USR, is provided to call sections of machine code. It has an advantage over a normal SYS call in that it can also pass data from BASIC into the floating point accumulator, so that it can be manipulated by a user-supplied machine code program before returning the result to the calling BASIC program. Before executing USR the address of a machine code subroutine must be seeded into USRADD, which is located at the two bytes starting at 785 ($0311).

A USR call can take two forms:

USR(NUM)

transfers the value assigned to the variable NUM (or any other specified variable) into FAC#1 before handing control to the machine code routine located at the vectored address in USRADD. Whereas:

A = USR(B)

places the contents of B into FAC#1, executes the machine code at USRADD and returns the final result, via FAC#1, in the variable B.

Let's have a look at a couple of simple examples to get things clear in our minds.

Program 37

```
10 REM * * USR DEMO * *
20 REM * * SET UP DUMMY MACHINE CODE * *
30 POKE 820,96 : REM RTS OPCODE
40 PRINT CHR$(147)
50 POKE 785,52 : REM SET UP USRADD TO
60 POKE 786,3 : REM POINT TO 820
70 A = 0 : B = 837
80 PRINT "PRE USR A = ";A
```

```
90  A = USR(B)
100 PRINT "POST USR A = ";A
```

This program begins by POKEing an RTS instruction into memory at location 820 (line 30). USRADD is then pointed to this location. The values of A and B are assigned (line 70) and the value of the former printed (line 80). The USR routine is then called (line 90) passing the value of B into FAC#1. The code pointed to by USRADD is then executed—it returns control immediately back to BASIC (remember it's just RTS) passing the value in FAC#1 into the variable A which is subsequently printed out (line 100).

We can modify this program slightly so that it actually does something! Add the following two lines:

```
25  POKE 820,230
26  POKE 821,98         REM INC $62
```

now change line 30 to read:

```
30  POKE 822,96     :   REM RTS
```

RUN the program. The printed result should be:

```
POST USR A = 841
```

which is 4 more than the value passed into it through B (which was 837). What happened here was that the two new bytes of machine code (lines 25 and 26) incremented the high byte of the FAC#1 mantissa located at location 98. But why should this add 4 rather than 1? Examining the binary will make things clearer. 837 is $0345 which is the value we were working on earlier. We know from our previous calculations that the byte stored in location 98 was $D1. Incrementing this gives $D2, therefore the four bytes of the FAC#1 mantissa read:

```
  $D2        $40        $00        $00
1101 0010  0100 0000  0000 0000  0000 0000
```

We also know from our earlier calculations that the exponential value was 2↑10. Floating the bicimal point ten places to the right to return to an un-normalized position gives:

```
1101001001.0000000000000000000000
```

Ignoring the non-significant zeros and sorting the binary into bytes we obtain:

```
0000 0011  0100 1001
   $03        049
```

and of course $0349 = 841.

The important point to remember when dealing directly with the FAC is that we are handling normalized values and even something as seemingly simple as an increment instruction will not have the obvious result!

Another important point to remember is that the contents of the FACs cannot be examined directly from BASIC by PEEKing locations. This is because even an operation as straightforward as PEEK will affect the FAC's contents. Therefore, to look at the contents of a FAC you need a machine code routine such as Program 38.

Program 38

```
10  REM * * SAVE FAC#1 * *
20  CODE = 49152
30  FOR LOOP = 0 TO 10
40    READ BYTE
```

```
50     POKE LOOP + CODE, BYTE
60   NEXT LOOP
70
80   REM * * M/C DATA * *
90   DATA 162,6         : REM $A2, $06         — LDX #6
100                       REM AGAIN
110  DATA 181,96        : REM $B5, $60         — LDA $60, X
120  DATA 157,52,3        REM $9D, $34, $03    — STA $0334, X
130  DATA 202             REM $CA              —DEX
140  DATA 208,248         REM $D0, $F8         — BNE AGAIN
150  DATA 96              REM $60              — RTS
160
170  PRINT CHR$(147)
180  POKE 785,0           REM SET USRADD POINTING
190  POKE 786,192         REM TO 49152 ($C000)
200  B = 837              REM VALUE TO PASS TO FAC#1
210  A = USR(B)           REM PASS AND EXECUTE CODE
220  PRINT "A = ";A
230  PRINT "FAC#1 = ";
240  FOR X = 1 TO 6
250  PRINT PEEK(820 + X);" ";
260  NEXT X
```

The machine code to save the contents of FAC#1 is quite simple, and just involves an indexing loop which first loads a byte into the accumulator and then stores it somewhere safe (lines 90 to 150). RUNing the program produces the following output:

```
A = 837
FAC#1 = 138 209 64 0 0 81
```

The first five bytes compare favourably with the calculated values above. The final byte is derived from FACSGN. The value 81 is $51 and in binary is 01010001. The sign bit, bit 7, is clear and denotes a positive number. We can change the sign to a negative value by 'forcing' bit 7 to 1. To do this we need to logically OR the contents of FACSGN with $80, 10000000 binary. Add the following lines to the program:

```
82  DATA 165,102   : REM $A5, $66     — LDA FACSGN
83  DATA 9,128     : REM $09, $80     — ORA #$80
84  DATA 133,102   : REM $85, $66     — STA FACSGN
```

and change the loop count to:

```
30  FOR LOOP = 0 TO 16
```

Now RUN the program. The result returned in A is now −837, while FACSGN returns 209.

INTEGER TO FLOATING POINT

Included in the built-in subroutines are several which allow numbers to be converted from integer to floating point and vice versa. These can be of great help in allowing us to manipulate multibyte numbers in machine code, so let's examine a few of them in operation.

Program 39 shows how an integer value can be converted into its normalized floating point counterpart. The subroutine to do this is located at 45969 ($B391). The integer value is expected to be found in the accumulator (high byte) and Y register (low byte)—on completion of the subroutine the floating point value can be extracted from FAC#1.

Program 39

```
10  REM * * INTEGER TO FP * *
20  CODE = 49152
30  FOR LOOP = 0 TO 17
40  READ BYTE
50    POKE LOOP + CODE, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 169,1            REM $A9, $01        — LDA #1
100 DATA 160,35         : REM $A0, $23        — LDY #$23
110 DATA 32,145,179     : REM $20, $91, $B3   — JSR $B391
120 DATA 162,6          : REM $A2, $06        — LDX #6
125                       REM AGAIN
130 DATA 181, 96          REM $B5, $60        — LDA $60, X
140 DATA 157,52,3         REM $9D, $34, $03   — STA $0334, X
150 DATA 202              REM $CA             — DEX
160 DATA 208,248        : REM $D0, $F8        — BNE AGAIN
170 DATA 96               REM $60             — RTS
180
190 PRINT CHR$(147)
200 SYS CODE
220 PRINT "FAC#1 = ";
230 FOR X = 1 TO 6
240   PRINT PEEK(820 + X);" ";
250 NEXT X
```

The integer value being converted here is $0123, and the high and low bytes are placed in the appropriate registers (lines 90 and 100) before the conversion routine is called (line 110). The floating point value is extracted from FAC#1 (lines 120 to 160) so that it can be PEEKed by the BASIC loop. RUNning the program produces this result:

FAC#1 = 137 145 128 0 0 0

Evaluating this, we have an exponent of 9 (137 − 128), and two bytes which in binary form give:

```
1001 0001   1000 0000
  145         128
```

Moving the bicimal point 9 places to the right we arrive at a final value of:

```
0000 0001 0010 0011
  $01        $23
```

$0123, which was our original value. The conversion works!

This subroutine for integer to floating point conversion can only handle numbers in the range 0 to 32767 ($7FFF). This is because bit 15 is used to determine the sign of the integer value to be converted. If clear then a positive value is assumed; if set a negative value is evaluated and the fact signalled in FACSGN. To see this, try changing the following lines:

```
90   DATA 169,255      REM $A9, $FF      — LDA #$FF
100  DATA 160,255      REM $A0, $FF      — LDY #$FF
```

RUN the program now and see what happens—I'll leave it up to you to work out how and why you got the result you did!

FLOATING POINT TO INTEGER

A subroutine which operates in the reverse direction, and converts a floating point value in FAC#1 to an integer one in the A and Y registers, is located at 45482 ($B1AA).

Program 40

```
10   REM * * FP TO INTEGER * *
20   CODE = 49152
30   FOR LOOP = 0 TO 17
40     READ BYTE
50     POKE LOOP + CODE, BYTE
60   NEXT LOOP
70
80   REM * * M/C DATA * *
90   DATA 162,6        REM $A2, $06          — LDX #6
100                    REM AGAIN
110  DATA 189,52,3     REM $BD, $34, $03     — LDA 820, X
120  DATA 149,96       REM $95, $60          — STA $60, X
130  DATA 202          REM $CA               — DEX
140  DATA 208,248      REM $D0, $F8          — BNE AGAIN
150  DATA 32,170,177   REM $20, $AA, $B1     — JSR $B1AA
160  DATA 133, 251     REM $85, $FB          — STA $FB
170  DATA 132,252      REM $84, $FC          — STY $FC
180  DATA 96           REM $60               — RTS
190
200  FOR X = 0 TO 5
210    READ FAC
```

```
220    POKE 821 + X, FAC
230  NEXT X
240  REM * * FAC DATA * *
250  DATA 137, 145, 128, 0, 0, 0
260  PRINT CHR$(147)
270  SYS CODE
280  PRINT "RESULTS RETURNED ARE:"
290  PRINT "ACCUMULATOR = "; PEEK(251)
300  PRINT "Y REGISTER = "; PEEK(252)
```

This program passes the normalized value of $0123 (line 250) into FAC#1. The DATA is READ by the loop in lines 210 to 230 and placed into unused memory from 820. The machine code begins by transferring this data into FAC#1 using indexed addressing (lines 90 to 140). Once there, the conversion routine is called (line 150) and the resultant values in the A and Y registers saved in zero page, from whence they can be PEEKed (lines 290 and 300). RUNning the program produces:

```
RESULTS RETURNED ARE:
ACCUMULATOR = 1
Y REGISTER = 35
```

Converting this to hex gives $0123!

FLOATING MEMORY

Several subroutines are available which allow floating point values to be transferred to and fro between either of the floating point accumulators and memory. However, before we can use these, we must see how floating point numbers are stored in memory, as a slightly different format is used. Let's go back to the normalized value of $0345 we used earlier, this was stored in the FAC as:

Exponent	$8A	1000 1010
Mantissa	$D1	1101 0001
	$40	0100 0000
	$00	0000 0000
	$00	0000 0000
Sign		0xxx xxxx

Looking at this, we can see that we waste 7 bits of the final sign byte simply because we only use bit 7 to denote the sign. If another way could be found of encoding this then the sign byte could be dispensed with.

You will remember that to normalize a floating point value the bicimal point is floated left continuously until it reaches the left-most 1. We know, therefore, that the first bit of the mantissa will *always* be a 1. As the BASIC Interpreter knows this too, it can 'forget' the 1 and use this bit to store the sign. When the interpreter converts a floating point number stored in memory (outside either floating point accumulator), it looks at the msb of the mantissa to evaluate the sign, then resets it back to 1 to evaluate the number proper! In memory, then, the normalized representation of $0345 is compacted into just 5 bytes stored thus:

Exponent	$8A	1000 1010	
Mantissa	$51	0101 0001	(bit 7 = 0 therefore number positive)
	$40	0100 0000	
	$00	0000 0000	
	$00	0000 0000	

THE SUBROUTINES

In all there are 33 floating point subroutines built-in to the BASIC Interpreter (well 33 that I have un-earthed!). It is important to remember that these subroutines are in no way 'standard' and their execution addresses could change if a new ROM is issued. For the same reason they are not transferrable to other CBM BASIC machines. However, if you're not going to be writing portable programs, and are interested only in getting the very most from your 64, then you won't be too worried!

All of these subroutines are now listed (by address) so that you can take full advantage of them. (PS Don't tell Commodore will you!)

$A9C4	Place FAC into variable pointed to by FORPNT (locations 73 and 74).
$A9D6	Place integer in FAC+3 into variable pointed to by FORPNT.
$AFA7	Evaluate function and return its numeric value in FAC. String pointer value in FAC+3.
$B1AA	Convert FAC to integer in A and Y.
$B391	Convert integer in A and Y to floating point value in FAC.
$B3A2	Convert integer in Y to floating point value in FAC.
$B7B5	Convert string pointed to by INDEX1 (locations 34 and 35) whose length is A, to a floating point value in FAC.
$B7F7	Convert FAC into an integer and store in INDEX1 (locations 34 and 35).
$B849	Add 0.5 to contents of FAC.
$B850	Subtract contents of FAC from floating point value in memory pointed to by A and Y. Place result in FAC.
$B867	Add contents of FAC to floating point value in memory location pointed to by A and Y. Place result in FAC.
$BA28	Multiply contents of FAC by contents of memory location pointed to by A and Y. Place result in FAC.
$BA30	Multiply contents of FAC by contents of AFAC. Place result in FAC.
$BA8C	Load AFAC with floating point value of memory pointed to by A and Y.
$BAB7	Test FAC/AFAC for multiplication underflow or overflow.
$BAE2	Multiply FAC by 10. Place result in FAC.
$BAFE	Divide FAC by 10. Place result in FAC.
$BB07	Divide contents of AFAC by contents of memory pointed to by A and Y with sign in X. Place result in FAC.
$BB0F	Divide contents of AFAC by contents of memory pointed to by A and Y. Place result in FAC.
$BB12	Divide contents of AFAC by contents of FAC. Place result in FAC, exponent in A.
$BBA2	Place floating point value in memory pointed to by A and Y, in FAC.

$BBC7	Store contents of FAC in locations 87 to 91.
$BBCA	Store contents of FAC in locations 92 to 96.
$BBD0	Store contents of FAC in locations pointed to by address in locations 73 and 74.
$BBD4	Store contents of FAC in memory location pointed to by A and Y.
$BBFC	Place contents of AFAC in FAC.
$BC0C	Place contents of FAC in AFAC.
$BC1B	Round off contents of FAC.
$BC2B	Return sign of contents of FAC in A. $00=zero, $01=positive, $FF=negative.
$BC3B	Store contents of A into FAC.
$BC5B	Compare contents of FAC with floating point value in memory pointed to by A and Y. Result of comparison returned in A. $00 values equal, $01 FAC > memory, $FF memory > FAC.
$BC9B	Convert contents of FAC into four byte integer. Place contents in FAC+1.
$BDD7	Print contents of FAC as an ASCII string.

20 The Kernal

At the very top of the Commodore 64's memory map, on page $FF, are the Kernal Operating System routines which allow user programs to communicate with, and take advantage of, the professionally written machine code already present in the ROM. In all, 39 Kernal routines are available, and an alphabetical list of these is given in Table 20.1. When any of these routines is called, normally with JSR, the Kernal performs either a direct or an indirect jump into the heart of the Kernal via a vectored address on Page Ø3 of block zero RAM. Table 20.2 lists these vectored addresses. This approach of jumping indirectly into the Kernal has been done for a deliberate reason. In the future, the BASIC may be revised or enhanced and this will probably mean that the routines within the Kernal will be moved around somewhat. As long as access to the Kernal routines is via the 'official' vector, machine code programs written for BASIC version X will also run on BASIC version Z, because they will all enter the Kernal at the same point, even though the actual sequence of events that occurs when they get there may change!

What follows now is a description of each one of the 39 Kernal routines—practical examples are included for the ones that you are more likely to use frequently.

ACPTR Get data from an IEEE serial bus.

Address	65445 ($FFA5)
Registers	accumulator and X register
Preparation	TALK, TKSA
Stack use	13 bytes

ACPTR is used to read a byte into the accumulator from a serial device such as a disc. Because this call uses *full handshaking* the serial device must first be told to transmit data using TALK. The X register is also used by this routine. Error checking should be handled by READST as errors are signalled in the status word.

Example:

```
PHA             \ save accumulator
TXA
PHA             \ save X register
LDA #2
JSR TALK        \ device 2 to talk
JSR ACPTR       \ read byte from serial bus
STA memory      \ save data byte
                \ continue until finished
PLA
TAX             \ restore X register
PLA             \ restore accumulator
```

Table 20.1 The Kernal routines

Name	Address Decimal	Address Hex	Description
ACPTR	65445	FFA5	Get byte from serial port
CHKIN	65478	FFC6	Open channel for input
CHKOUT	65481	FFC9	Open channel for output
CHRIN	65487	FFCF	Input character from channel
CHROUT	65490	FFD2	Output character to channel
CINT	65409	FF81	Reset screen editor
CIOUT	65448	FFA8	Put byte to serial port
CLALL	65511	FFE7	Close all files and channels
CLOSE	65475	FFC3	Close specified logical file
CLRCHN	65484	FFCC	Close input and output channels
GETIN	65508	FFE4	Get character from keyboard buffer
IOBASE	65523	FFF3	Get base address of I/O devices
IOINIT	65412	FF84	Reset input/output
LISTEN	65457	FFB1	Command serial bus devices to listen
LOAD	65493	FFD5	LOAD memory from device
MEMBOT	65436	FF9C	Read/set bottom of memory
MEMTOP	65433	FF99	Read/set top of memory
OPEN	65472	FFC0	Open a logical file
PLOT	65520	FFF0	Read/set XY cursor position
RAMTAS	65415	FF87	Reset RAM
RDTIM	65502	FFDE	Read real time clock
READST	65463	FFB7	Read I/O status word
RESTOR	65418	FF8A	Reset I/O vectors
SAVE	65496	FFD8	Save memory block to device
SCNKEY	65439	FF9F	Scan keyboard
SCREEN	65517	FFED	Return XY details of screen
SECOND	65427	FF93	Send second address after LISTEN
SETLFS	65466	FFBA	Set logical first and second address
SETMSG	65424	FF90	Control Kernal messages
SETNAM	65469	FFBD	Set file name
SETTIM	65499	FFDB	Set real time clock
SETTMO	65442	FFA2	Set timeout on serial bus
STOP	65505	FFE1	Scan STOP key
TALK	65460	FFB4	Instruct serial bus device to TALK
TKSA	65430	FF96	Send secondary address after TALK
UDTIM	65514	FFEA	Increment real time clock
UNLSN	65454	FFAE	Command serial bus to unLISTEN
UNTLK	65451	FFAB	Command serial bus to unTALK
VECTOR	65421	FF8D	Read/set vectored I/O

CHKIN Open a channel for input.

Address	65478 ($FFC6)
Registers	X register, accumulator
Preparation	(OPEN)
Stack use	none

CHKIN is used to define an input channel from a previously OPENed logical file, thus allowing it to be read. The X register is used to hold the logical file number, the

Table 20.2 Vectored addresses

Name	Address		Vector
	Decimal	Hex	
ADRAY1	3–4	0003-0004	Covert FP to integer
ADRAY2	5–6	0005-0006	Convert integer to FP
INPPTR	67–68	0043-0044	INPUT routine
KEYTAB	243–244	00F5-00F6	Keyboard decode table
IERROR	768–769	0300-0301	BASIC error message
IMAIN	770–771	0302-0303	BASIC warm start
ICRNCH	772–773	0304-0305	BASIC tokenizer
IQPLOP	774–775	0306-0307	BASIC list
IGONE	776–777	0308-0309	Character dispatch
IEVAL	778–779	030A-030B	BASIC token evaluation
USRADD	785–786	0311-0312	USR address (784 holds $4C)
CINV	788–789	0314-0315	Hardware IRQ
CBINV	790–791	0316-0317	BRK vector
NMINV	792–793	0318-0319	NMI vector
IOPEN	794–795	031A-031B	OPEN vector
ICLOSE	796–797	031C-031D	CLOSE vector
ICHKIN	798–799	031E-031F	CHKIN vector
ICKOUT	800–801	0320-0321	CHKOUT vector
ICLRCH	802–803	0322-0323	CLRCHN vector
IBASIN	804–805	0324-0325	CHRIN vector
IBSOUT	806–807	0326-0327	CHROUT vector
ISTOP	808–809	0328-0329	STOP vector
IGETIN	810–811	032A-032B	GETIN vector
ICLALL	812–813	032C-032D	CLALL vector
USRCMD	814–815	032E-032F	User-defined vector
ILOAD	816–817	0330-0331	LOAD vector
ISAVE	818–819	0332-0333	SAVE vector

accumulator is also used. This routine *must* be called before using either the CHRIN or GETIN routines if data is being input from any device other than the keyboard.

Note that this routine will automatically send a TALK address if the communicating device is present on the serial bus. A secondary address will also be sent if so specified in the OPEN routine.

There are three possible errors:

#3 File is not OPEN
#5 No device present
#6 File not an input file!

CHKOUT Open a channel for output.

Address	65481 ($FFC9)
Registers	X register, accumulator
Preparation	(OPEN)
Stack use	4 bytes minimum

CHKOUT defines a previously OPENed file for output so that it may have data written to it. The X register should contain the file number; the accumulator is also used. This routine *must* be used prior to sending data to another device. CHKOUT will automatically send a LISTEN address if the device is present on the serial bus.

Note it is not necessary to call this routine to ouput data to the screen.

There are three possible errors:

- #3 No file open
- #5 No device present
- #7 No output file present!

CHRIN Input a character from the input channel.

Address	65487 ($FFCF)
Registers	accumulator, X register
Preparation	(OPEN, CHKIN)
Stack use	7 bytes minimum

CHRIN reads a byte of data into the accumulator from the channel already open for input. If CHKIN has not been called to define an input channel the keyboard will be used as a default channel.

This routine can be used to manipulate data already present in the keyboard buffer—for example, to move the keyboard buffer into the tape buffer. As the X register is required by CHRIN, the Y register must be used for indexing:

```
        PHA                 \ save accumulator
        TXA
        PHA                 \ save X register
        LDY #0              \ initialize Y register as offset counter
LOOP    JSR CHRIN           \ remove character
        STA TAPE, Y         \ place in tape buffer
        INY                 \ increment Y
        CMP #13             \ does accumulator hold CR?
        BNE LOOP            \ no, so repeat
        PLA
        TXA                 \ restore X register
        PLA                 \ restore accumulator
```

CHROUT Output character in accumulator to channel.

Address	65490 ($FFD2)
Registers	accumulator
Preparation	(CHKOUT, OPEN)
Stack use	8 bytes minimum

This routine can be used to print ASCII characters to the screen as this is the default ouput device. Other devices can be set up by calling the OPEN and CHKOUT routines. The character to be output should be placed into the accumulator. The following example shows how a string of characters can be printed to the screen.

```
        PHA                 \ save accumulator
        LDY #0              \ initialize counter
```

```
LOOP    LDA WORD, Y          \ get byte
        JSR CHROUT           \ print it
        INY                  \ increment counter
        CMP #13              \ was last character a CR?
        BNE LOOP             \ no repeat
        PLA                  \ restore accumulator
        RTS
        .WORD COMMODORE 64 <CR>
```

CINT Reset screen editor and VIC.

Address	65409 ($FF81)
Registers	none
Preparation	none
Stack use	4 bytes

This routine is used to reset the screen editor and VIC chip—perhaps after high resolution graphics have been used, or as part of a cartridge initialization routine.

CIOUT Output byte to device on serial bus.

Address	65448 ($FFA8)
Registers	accumulator
Preparation	LISTEN, (SECOND)
Stack use	5 bytes

CIOUT writes the byte currently held in the accumulator to a device present on the IEEE serial bus using full serial handshaking. To ensure that the device is ready to receive data the LISTEN call must be used first; SECOND may be used to send a secondary address.

CLALL Close all files.

Address	65511 ($FFE7)
Registers	accumulator, X register
Preparation	none
Stack use	11 bytes

This routine closes all files that are currently open. CLALL also calls CLRCHN to reset the input/output channels.

CLOSE Close logical file.

Address	65475 ($FFC3)
Registers	accumulator, X register, Y register
Preparation	none
Stack use	2 bytes minimum

This routine is used to close a specified logical file—the file number being in the accumulator (this must be the same number that the file was OPENed with). Errors are 0 and 240 and should be handled by calling READST.

CLRCHN Close all input/output channels.

Address	65484 ($FFCC)
Registers	none
Preparation	none
Stack use	9 bytes

This routine is called to restore all input/output channels to their default values. The default input device is the keyboard (device #Ø) and the default output device is the screen (device #3). If one of the devices being closed is on the serial bus this routine will also call UNTALK or UNLISTEN. CLRCHN is automatically called by CLALL.

GETIN Get a character from keyboard.

Address	655Ø8 ($FFE4)
Register	accumulator
Preparation	CHKIN, OPEN
Stack use	7 bytes minimum

This routine gets one character from the keyboard queue and places it in the accumulator. Characters may also be read in from the RS232 port. If no character is found in the queue then the accumulator returns the value Ø. The following example shows how you can wait for a key to be pressed:

```
WAIT    JSR GETIN       \ get character
        BEQ WAIT        \ if empty repeat
```

Alternatively, a specific character (or sequence of characters) can be looked for. The following routine will only continue if the numbers 6 and 4 are entered one after the other:

```
SIX     JSR GETIN       \ get first character
        BEQ SIX         \ repeat if empty
        CMP #ASC"6"     \ is it a six?
        BNE SIX         \ no, restart!
FOUR    JSR GETIN       \ yes, get next character
        BEQ FOUR        \ repeat if empty
        CMP #ASC"4"     \ is it a four?
        BNE SIX         \ no, restart from beginning
                        \ yes, all systems go!
```

IOBASE Read address of 6526 CIA.

Address	65523 ($FFF3)
Registers	X and Y registers
Preparation	none
Stack use	2 bytes

When called, this routine returns the 16-bit address where the 6526 CIA is located, in the index registers. The X register holds the low byte address and the Y register the high order byte. The address returned for the Commodore 64 is $DCØØ.

IOINIT Reset all input/output devices.

Address	65412 ($FF84)
Registers	accumulator
Preparation	none
Stack use	none

This routine is used to restore all input/output devices to their usual conditions.

LISTEN Command serial bus device to LISTEN.

Address	65457 ($FFB1)
Registers	accumulator
Preparation	none
Stack use	none

The device on the serial bus specified by the number in the accumulator is commanded to receive data. The device number is in the range Ø to 31. Errors should be handled by READST.

LOAD Load memory from device into RAM.

Address	65493 ($FFD5)
Registers	accumulator, X register, Y register
Preparation	SETLFS, SETNAM
Stack use	none

This routine can be used to load or verify a block of memory from an input device (tape, for example). The accumulator holds the command code—Ø signals LOAD, 1 signals VERIFY. The SETLFS and SETNAM routines must be called first.

If a relocation of the load is required the SETLFS routine should be used to send a secondary address of Ø, and the index registers must hold the reload start address. If the device is addressed with a secondary address of 1 then the data is loaded at the address given by the header.

Example:

```
                            \ load file from tape
                            \ call SETLFS and SETNAM first
LDA #Ø                      \ set LOAD flag
LDX #$ØØ                    \ set reload address if required . . .
LDY #$CØ                    \ . . . this is 'free' RAM
JSR LOAD                    \ load memory
STX TEMP                    \ index registers now hold highest address
STY TEMP+1                  \ loaded—save if needed
```

Errors returned are Ø, 4, 5, 8, 9 (see READST).

MEMBOT Set bottom of memory.

Address	65436 ($FF9C)
Registers	both index registers
Preparation	none
stack use	none

This routine can be used to either read or set the bottom of memory, depending on the condition of the Carry flag. If carry is set then the address of the bottom of memory is returned in the X and Y registers. If carry is clear on entry to this routine, the values in the index registers are interpreted as an address and are loaded into the MEMBOT pointer which points to the bottom of RAM. This routine can be used to create 'safe' machine code space by moving the MEMBOT pointer up the memory map (say 512 bytes up), as the following example shows:

```
                          \ read current pointer
SEC                       \ set Carry flag
JSR MEMBOT                \ pointer in X and Y
INY
INY                       \ increment page by two
CLC                       \ clear Carry flag
JSR MEMBOT                \ rewrite MEMBOT
```

MEMTOP Set the top of RAM

Address	65433 ($FF99)
Registers	both index registers
Preparation	none
Stack use	2 bytes

This routine can be used to either read or set the bottom of memory depending on the condition of the Carry flag. If carry is set then the address of the top of memory is returned in the X and Y registers. If the Carry flag is clear on entry to this routine the values in the index registers are interpreted as an address, and are loaded into the MEMTOP pointer which points to the top of RAM.

OPEN Open a logical file.

Address	65472 ($FFC0)
Registers	accumulator, X register, Y register
Preparation	SETLFS, SETNAM
Stack use	none

This routine is used to OPEN a logical file for input or output operations. Both SETLFS and SETNAM must be used prior to the OPEN routine. The following example shows how the BASIC equivalent of OPEN 1, 1, 1, "NAME" can be implemented:

```
LDA #4                    \ length of file name
LDY #$C0                  \ high byte address filename
LDX #0                    \ low byte address filename
JSR SETNAM                \ write filename
LDA #1
LDY #1
LDX #1
JSR SETLFS
JSR OPEN
```

PLOT Read/set cursor position.

Address	65520 ($FFF0)
Registers	accumulator, X register, Y register
Preparation	none
Stack use	2 bytes

This routine can be used to read or set the cursor position depending on the condition of the Carry flag. If carry is set the X and Y coordinates of the cursor are loaded into the X and Y registers respectively. If carry is clear then the contents of the X and Y registers are used to reposition the cursor at the new X, Y coordinates. The following example shows how this routine can be used—in this case to move the cursor across and down one position:

```
SEC              \ set carry
JSR PLOT         \ read cursor coordinates
INX              \ add one to X coordinate
INY              \ add one to Y coordinate
JSR PLOT         \ reposition cursor
```

RAMTAS Perform RAM test.

Address	65415 ($FF87)
Registers	accumulator, X register, Y register
Preparation	none
Stack use	2 bytes

This routine tests RAM and sets the top and bottom memory pointers respectively. Locations $0000–$0101 and $0200–$03FF are cleared. The screen base is set to $0400 and a non-destructive RAM test is carried out above this location.

RDTIM Read system clock.

Address	65502 ($FFDE)
Registers	accumulator, X register, Y register
Preparation	none
Stack use	2 bytes

This routine can be used to read the system (jiffy) clock which 'ticks' every 60th second. The accumulator returns the most significant byte, the X register the next most significant and the Y register the least significant byte. The jiffy clock is maintained in locations $A0, $A1 and $A2 though these locations should not be read directly.

Example:

```
JSR RDTIM        \ read jiffy clock
STA $FB          \ save time in zero page
STX $FC
STY $FD
```

READST Read status word.

Address	65463 ($FFB7)
Registers	accumulator
Preparation	none
Stack use	2 bytes

This routine returns the current status of an input/output device. Status is returned as a single-byte bit pattern in the accumulator. This routine should generally be called on completion of any input/output procedure which might cause an error. The errors associated with particular bits are shown in Table 20.3.

Table 20.3

Bit	Cassette read	Serial RW	Tape verify/load
0		Time-out write	
1		Time-out read	
2	Short block		Short block
3	Long block		Long block
4	Read error		Mismatch
5	Checksum error		Checksum error
6	End of file	EOI line	
7	End of tape	No device present	End of tape

For example, the following routine can be used to check a tape load for checksum errors:

```
JSR READST
AND #$20                    \ checksum?
BEQ ERROR                   \ yes, call, handling routine
```

RESTOR Reset all system default vectors.

Address	65418 ($FF8A)
Registers	accumulator, X register, Y register
Preparation	none
Stack use	2 bytes

All system vectors used in Kernal and BASIC, plus the interrupt vectors, are reset to their default values.

SAVE Save memory block to device.

Address	65496 ($FFD8)
Registers	accumulator, X register, Y register
Preparation	SETLFS, SETNAM
Stack use	none

The accumulator points to a zero page vector specifying the start address of the memory to be saved, and the index registers hold the end address. The SETLFS and SETNAM routines must be used prior to SAVE. Note that a filename is not needed when saving to tape (device 1).

The following routine shows how a section of memory stored from $C000 to $C12A may be saved to tape:

```
LDA #1                      \ device 1 therefore tape
JSR SETLFS
LDA #5                      \ filename 5 characters long i.e. "FILE1"
LDX #LOW                    \ load low byte address of filename
LDY #HIGH                   \ load high byte address of filename
JSR SETNAM                  \ write filename
LDA #00                     \ low byte start
STA $FB
LDA #$C0                    \ high byte start
STA $FC
LDA #$FB                    \ point accumulator to START address
```

```
LDX #$2A        \ low byte END address
LDY #$C1        \ high byte END address
JSR SAVE        \ save memory block
```

SCNKEY Scan the keyboard.

Address	65439 ($FF9F)
Registers	accumulator, X register, Y register
Preparation	IOINIT
Stack use	5 bytes

This routine scans the keyboard looking for a 'depressed' key. If such a key is detected its ASCII code is placed into the normal keyboard queue for processing. The following example shows how a machine code program can truly handle input from the keyboard:

```
KEY  JSR SCNKEY     \ scan keyboard
     JSR GETIN      \ get character
     BEQ KEY        \ branch if no key present
```

SCREEN Returns screen set-up.

Address	65517 ($FFED)
Registers	X register, Y register
Preparation	none
Stack use	2 bytes

This routine returns the number of columns in the X register and number of lines in the Y register.

SECOND Send secondary address for LISTEN.

Address	65427 ($FF93)
Registers	accumulator
Preparation	LISTEN
Stack use	8 bytes

This routine is used to send a secondary address on the serial bus following a call to the LISTEN routine. Errors are indicated in the status byte.

SETLFS Set up a logical file.

Address	65466 ($FFBA)
Registers	accumulator, X register, Y register
Preparation	none
Stack use	2 bytes

This routine will normally be called during the initialization of input/output by other routines. It is used to declare the logical file number, device number and secondary address (command number). These are placed in the accumulator, X register and Y register respectively. If no secondary address is to be sent then the Y register should contain 255 ($FF).

To set up the printer as logical device number 3, and to send a secondary address of 7 so that it will print in lower case, use the following:

```
LDA #3     \ logical file 3
LDX #4     \ select serial bus printer
```

```
LDY #7          \ lower case
JSR SETLFS
```

SETMSG Control messages.

Address	65424 ($FF90)
Registers	accumulator
Preparation	none
Stack use	2 bytes

This routine governs control and error messages. Bits 6 and 7 of the accumulator indicate the message's origin. If bit 7 is set an error message will be printed from the Kernal, i.e. 'FILE NOT FOUND'. If bit 6 is set, a control message is output, i.e. 'PRESS PLAY ON CASSETTE'.

Messages can be enabled or disabled as follows:

```
LDA #0
JSR SETMSG          \ turn off all messages
LDA #40             \ 0100 0000 bit 6 on
JSR SETMSG          \ control messages only
LDA #80             \ 1000 0000 bit 7 on
JSR SETMSG          \ error messages only
```

SETNAM Setup filename.

Address	65469 ($FFBD)
Registers	accumulator, X register, Y register
Preparation	none
Stack use	none

This routine is used to set up a filename for use by the OPEN, SAVE or LOAD routines. The length of the filename is loaded into the accumulator and the index registers are used to hold the address where the filename is stored—low byte in X register high byte in Y register. If no filename is required the accumulator can be set to 0 and the index register's contents are ignored.

To set the filename as 'RETURNS', which is stored as an ASCII string at $0334, the following could be used:

```
LDA #7              \ filename length
LDX #$34            \ low byte filename address
LDY #$03            \ high byte filename address
JSR SETNAM
```

SETTIM Set the system clock.

Address	65499 ($FFDB)
Registers	accumulator, X register, Y register
Preparation	none
Stack use	2 bytes

This routine is used to set the system jiffy clock. Three bytes are expected by the routine, the most significant byte is placed into the accumulator, the next in the X register and the least significant in the Y register.

SETTMO Set time-out on serial bus.

Address	65442 ($FFA2)
Registers	accumulator
Preparation	none
Stack use	2 bytes

This routine can be used to set or reset the time-out flag for the IEEE serial bus.

STOP Test for STOP key being pressed.

Address	65505 ($FFE1)
Registers	accumulator, X register
Preparation	none
Stack use	none

If the STOP key is detected during a keyboard scan the Zero flag is set. If the STOP key is not detected, then the accumulator holds a byte corresponding to the very last row of the keyboard scan.

TALK Instruct the serial bus device to TALK.

Address	65460 ($FFB4)
Registers	accumulator
Preparation	none
Stack use	8 bytes

The accumulator should contain the number which corresponds to the device about to be asked to TALK. Check status byte for errors.

TKSA Send secondary address after TALK.

Address	65430 ($FF96)
Registers	accumulator
Preparation	TALK
Stack use	8 bytes

This routine is used to send a secondary address on the serial bus to the TALKing device. The status byte should be checked for errors.

UDTIM Increment system clock.

Address	65514 ($FFEA)
Registers	accumulator, X register
Preparation	none
Stack use	2 bytes

This routine simply increments the system jiffy clock by one sixtieth of a second.

UNLSN Command serial device to unLISTEN.

Address	65454 ($FFAE)
Registers	accumulator
Preparation	none
Stack use	8 bytes

This routine instructs all devices that are currently LISTENing on the serial bus to stop doing so! Use READST to check for errors.

UNTLK Command serial device to unTALK.

Address	65451 ($FFAB)
Registers	accumulator
Preparation	none
Stack use	8 bytes

Instructs all devices currently TALKing on serial bus to stop doing so. Error checks may be performed on status byte.

VECTOR Read/set vectors.

Address	65421 ($FF8D)
Registers	accumulator, X register, Y register
Preparation	none
Stack use	2 bytes

Depending on the condition of the Carry flag the system vectors will either be read or reset. Calling the routine with carry set causes the system vectors to be stored in the section of memory pointed to by the address held in the index registers. If the Carry flag is clear, the list pointed to by the index registers is copied into the system vectors.

21 Speeding Up and Slowing Down

At the beginning of this book I said that one of the advantages of using machine code was that it runs very much faster than an interpreted language such as BASIC. But just how fast is fast, and can we calculate the amount of time a piece of machine code takes to execute? The answer is yes, and we shall now see just how to do it.

The Commodore 64 has within its plastic case its own clock (called the jiffy clock) which it uses to 'tick' out the stages of an instruction's execution. This clock takes the form of a quartz crystal which vibrates at a rate of 2MHz, which simply means it 'ticks' or *cycles* 2 million times every second. Appendix 4 lists the number of cycles each instruction requires. As can be clearly seen, the more complex forms of addressing modes take longer to execute. The fastest instructions, generally employing implied or immediate addressing, take just 2 cycles to complete. In real terms this is 0.000001 seconds or more simply, a micro second—one millionth of a second! Instructions which access absolute addresses can vary in execution time. For example, instructions using absolute indexed addressing will generally take 4 cycles to complete, but, if a memory page boundary is crossed an extra cycle is required in order to increment the high byte of the Program Counter (PCH).

Branch instructions can take 2, 3 or 4 cycles. If the branch does not take place, then only two cycles are needed. Three cycles are needed if the branch occurs, and a further cycle if a page boundary is crossed.

Another interesting point to note is that while PHA and STA ZEROPAGE both take 3 cycles, PLA takes 4 cycles compared with LDA ZEROPAGE which only takes 3 cycles. It is therefore quicker to use zero page for storage rather than the stack. It should be remembered, though, that PHA : PLA require only two bytes whereas STA ZEROPAGE: LDA ZEROPAGE require four—so there has to be a trade-off in memory requirements against execution time.

Using Appendix 4 (page 181) we can calculate some program execution times.

```
LDX #$FF         \ immediate
TXA              \ implied
AND $FB          \ zero page
STA $1500, X     \ absolute indexed
JMP ($FC)        \ indirect
```

The first instruction, LDA #$FF, uses immediate addressing and therefore requires only 2 cycles. Similarly the implied TXA instruction needs only 2 cycles. AND $FB takes a little longer, 3 cycles, as it has to access the contents of a zero page location. The absolute indexed addressing of STA $1500, X can take either 4 or 5 cycles, depending on whether a page boundary is crossed. The shorter time is the correct one here because the base address ($1500) is itself on a page boundary, which means the index register cannot contain a value great enough to cross the next page boundary. Finally, the indirect jump takes 3 cycles. The total time of program operation is therefore 2 + 2 + 3 + 4 + 3 = 14 cycles.

Consider the following simple loop.

```
        LDY #$FF        \ 2 cycles
LOOP    DEY             \ 2 cycles
        BNE LOOP        \ 3 cycles
```

The Y register loading instruction takes 2 cycles and the loop execution a total of 5 cycles. However, the LOOP will execute 255 times and we must of course take this into account. This gives a total LOOP execution period of 5 × 255 − 1 = 1274 cycles. The 'minus one' in the calculation is because the 'last' branch will not occur and will therefore only require 2 cycles of computer time. If the branch causes a page boundary crossing, then each execution of LOOP will need 6 cycles, giving a total of 6 × 255 − 2 = 1528 cycles for the program (the 'minus two', of course, is for the last 'page boundary branch' which does not take place).

Because of the speed of machine code it is sometimes necessary to produce deliberate delays to slow things down to allow mere humans time to interact with the Commodore 64. There is an instruction that does nothing but provide a 2 cycle delay:

NOP   No operation

To demonstrate its use let's write a piece of machine code to produce about a one millisecond delay (0.001 seconds or 2000 cycles). The process has to be worked out by trial and error. Using the loop described above and inserting a single NOP command would give:

```
        LDY #$FF        \ 2 cycles
LOOP    NOP             \ 2 cycles
        DEY             \ 2 cycles
        BNE LOOP        \ 3 cycles
```

Total loop time is 7 cycles, which gives a total execution time of 7 × 255 − 1 = 1784 cycles. Because LDY #$FF is fundamental to the LOOP operation we should include this—giving a total delay of 1786 cycles. This falls short of the desired 2000 cycles.

By adding an extra NOP, the delay is increased to 9 × 255 − 1 + 2 = 2296 cycles. This is too high but can be reduced by altering the value of the loop counter.

```
        LDY #$DE        \ 2 cycles
LOOP    NOP             \ 2 cycles
        NOP             \ 2 cycles
        DEY             \ 2 cycles
        BNE LOOP        \ 3 cycles
```

This final version produces a delay which is just one half of one millionth of a second short of a millisecond i.e. 9 × 222 − 1 + 2 = 1999 cycles. You might like to try experimenting with loops to produce a delay of exactly one millisecond.

22 Interrupts and Breaks

INTERRUPTS

An interrupt is a signal that causes the program that is currently running to halt temporarily whilst program control is transferred to a subroutine somewhere in memory that is designed to *service* the interrupt. Once the interrupt has been dealt with control is passed back to the original program, allowing it to continue as though nothing had happened.

There are two different types of interrupt—the NMI (non-maskable interrupt) and the IRQ (interrupt request). The difference between the two is that an NMI must be serviced immediately because it is too important to ignore, whereas an IRQ can be ignored until we are ready to service it. A variety of different devices can interrupt the 651Ø, some obvious examples being devices attached to the user port or games port.

On the Commodore 64, the NMI is used by the Kernal Operating System to communicate with various devices on- and off-board. As this type of interrupt cannot be 'programmed' directly it is not specifically covered here—though much of what follows is applicable. The IRQ has two instructions associated with it which directly affect bit 2 of the Status register, they are:

CLI	Clear interrupt disable bit
SEI	Set interrupt disable bit

The condition of the Interrupt flag within the Status register determines whether the IRQ is serviced or ignored when it occurs. If the Interrupt bit is set (I=1) then an IRQ is ignored; if the Interrupt bit is clear (I=Ø) an IRQ is serviced the moment it occurs.

Let's examine the exact sequence of events that takes place when an IRQ occurs, assuming that the Interrupt flag is clear. Firstly, the processor completes the operation specified by the machine level instruction it is currently executing. The Status register is examined to determine if bit 2 is clear (in our case it is), in which case the contents of the Program Counter and Status register are pushed on to the hardware stack. The Interrupt bit is now set (I=1) to shut out any further IRQs whilst one is being serviced. Note that the Interrupt bit is set *after* the Status register has been saved, thus preserving its pre-interrupt condition. At the end of this chain of events, the Program Counter is loaded with the contents of the locations $FFFE and $FFFF, the top two bytes in the memory map, and a jump performed to this address. The machine code located here (65352 in BASIC V2 machines) is listed below, and ends with a jump to the actual *Interrupt service routine* responsible for locating and servicing the IRQ.

The IRQ routine also has a vector in block zero RAM associated with it—at 788 ($Ø314)—and any user-generated interrupt routines should gain control through here. On completion of the interrupt service routine, control must be returned to the interrupted program. To facilitate this a further instruction is provided:

RTI Return from interrupt

This instruction resets the Status register and Program Counter to the values previously saved on the stack, and allows the original program to continue from the point at which it was interrupted.

Before performing the indirect jump to the IRQ vector the Kernal also saves the contents of the other registers. This is very important because they will undoubtedly be altered by the interrupt service routine, and we need to ensure that the contents of *all* registers are in their pre-interrupt condition before the RTI is executed. The machine code located at 65352 responsible for this reads as follows:

```
65352   PHA              \ save accumulator on stack
65353   TXA
65354   PHA              \ save X register on stack
65355   TYA
65356   PHA              \ save Y register on stack
65357   TSX              \ transfer Stack Pointer to X register
65358   LDA 260, X       \ get Status register
65361   AND #16          \ mask off high nibble
65363   BEQ +3           \ if Z = 1 then IRQ
65365   JMP (790)
65368   JMP (788)        \ jump to IRQ service
```

As you can see, the accumulator and index registers are pushed on to the stack *before* jumping to the IRQ vector—any user-supplied routines should act on this and handle them as required. Several bytes in Page 03 are reserved as store locations for the registers (see Table 22.1), and user-supplied routines can also use these if stack space is at a premium. (The JMP (790) instruction is described in the next section—BREAKS.)

Table 22.1

Label	Address	Description
SAREG	780 ($030C)	Accumulator store
SXREG	781 ($030D)	X register storage
SYREG	782 ($030E)	Y register storage
SPREG	783 ($030F)	Stack Pointer storage

The Commodore 64's keyboard is interrupt driven. Every time you press a key an interrupt service routine is used to store the depressed key's value into the keyboard buffer for servicing. As an active example enter the following one line program:

```
10 FOR N=0 TO 2000 : NEXT N
```

Type RUN and hit a few keys on the keyboard while this nonsense loop is being executed. When the loop has finished the keys you pressed previously appear on the screen, proving that you interrupted the program at machine level whilst it was running.

BREAKS

There is an instruction in the Commodore 64's 6510 instruction set which allows a software type of interrupt to be generated—this instruction is:

BRK Break

BRK is a single byte instruction (opcode $00) which can be inserted into programs as and when required. When the 6510 encounters a BRK instruction it does a number of things—in fact, it proceeds along a similar path to that taken by an IRQ. Firstly it increments the Program Counter so that it is now pointing to the instruction after the BRK, and then pushes this two byte address on to the hardware stack. Next it sets the Break flag, which is bit 4 of the Status register, and then pushes this on to the stack before jumping to the BRK servicing routine. This routine's address is stored in locations $FFFE and $FFFF and therefore it is the same servicing routine as that used by an IRQ. Or is it? Well not exactly—it just enters at the same point. Referring to the interrupt service routine address 65361, the high byte of the Status register, now in the accumulator, is masked off by the AND #16 instruction. Now if a BRK had occurred, bit 4 (the Break flag) would be set and the BEQ would not take place. Instead, there would be an indirect jump to the BRK vector at 790.

By resetting the BRK vector it is possible to perform simple machine code debugging by pointing the BRK handler to a user-supplied routine that prints out the contents of all the processor's registers at the time the BRK occurred.

23 Prepacked Utilities

I am sure that you will find the programs that follow in this chapter very useful when you write your own serious machine code—thus I have called them utility programs because they have a practical use. Included are programs to:

1. Convert an ASCII based hex number into its binary equivalent.
2. Convert and print a binary value as a two digit ASCII based hex number.
3. Print an ASCII string stored within the machine code itself.

HEX TO BINARY CONVERSION

The following routine will convert two ASCII based hexadecimal characters into their eight bit binary equivalent. For example, if the characters F E are input, the binary value returned would be 1111 1110—this will of course be printed as 254, the decimal equivalent. This is a particularly important procedure especially if programs handling hexadecimal data are anticipated. Conversion is not difficult and Table 23.1 gives some indication of what is required.

Table 23.1

Hex character	Binary value	ASCII value	ASCII binary
0	0000	$30	0011 0000
1	0001	$31	0011 0001
2	0010	$32	0011 0010
3	0011	$33	0011 0011
4	0100	$34	0011 0100
5	0101	$35	0011 0101
6	0110	$36	0011 0110
7	0111	$37	0011 0111
8	1000	$38	0011 1000
9	1001	$39	0011 1001
A	1010	$41	0100 0001
B	1011	$42	0100 0010
C	1100	$43	0100 0011
D	1101	$44	0100 0100
E	1110	$45	0100 0101
F	1111	$46	0100 0110

In the case of the characters 0 to 9 it should be fairly obvious that all we need to do to convert them to binary is to mask out the high nibble of the character's ASCII code, because the low nibble binary is the same as the hex character itself.

Converting the characters A to F is a little less obvious. However, if the high nibble of the ASCII code is masked off, then the remaining low nibble is 9 less than the hex value required. For example, the ASCII for 'D' is 01000100, masking off the high nibble gives 0100, which is 4, add 9 to this to arrive at $D = 1101.

Program 41

```
 10  REM * * ASCII HEX TO BINARY * *
 20  CODE = 49152
 30  FOR LOOP =0 TO 48
 40    READ BYTE
 50    POKE CODE + LOOP, BYTE
 60  NEXT LOOP
 70
 80  REM * * M/C DATA * *
 90  DATA 32,34,192       REM $20, $22, $C0    — JSR CHARACTER
100  DATA 165,252       : REM $A5, $FC         — LDA $FC
110  DATA 32,24,192     : REM $20, $18, $C0    — JSR CHECK
120  DATA 10            : REM $0A              — ASL A
130  DATA 10            : REM $0A              — ASL A
140  DATA 10            : REM $0A              — ASL A
150  DATA 10            : REM $0A              — ASL A
160  DATA 133,253       : REM $85, $FD         — STA $FD
170  DATA 165,251       : REM $A5, $FB         — LDA $FB
180  DATA 32,24,192     : REM $20, $18, $C0    — JSR CHECK
190  DATA 5,253         : REM $05, $FD         — ORA $FD
200  DATA 133,254       : REM $85, $FE         — STA $FD
210  DATA 96            : REM $60              — RTS
220  REM * * CHECK SUBROUTINE : $C018 * *
230  DATA 201,58        : REM $C9, $3A         — CMP #$3A
240  DATA 176,3         : REM $B0, $03         — BCS ATOF
250  DATA 41,15         : REM $29, $0F         — AND #$0F
260  DATA 96            : REM $60              — RTS
270                       REM ATOF
280  DATA 233,55        : REM $E9, $37         — SBC #$37
290  DATA 96            : REM $60              — RTS
300  REM * * CHARACTER SUBROUTINE : $C022 * *
310                       REM FIRST
320  DATA 32,228,255    : REM $20, $E4, $FF    — JSR $FFE4
330  DATA 240,251       : REM $F0, $FB         — BEQ FIRST
340  DATA 133,252       : REM $85, $FC         — STA $FC
```

```
350                           REM SECOND
360  DATA 32,228,255          REM $20, $E4, $FF    — JSR $FFE4
370  DATA 240,251             REM $F0, $FB         — BEQ SECOND
380  DATA 133,251             REM $85, $FB         — STA $FB
390  DATA 96                  REM $60              — RTS
400
410  PRINT CHR$(147)
420  PRINT "ENTER TWO HEX DIGITS";
430  SYS CODE
440  PRINT "THEIR BINARY VALUE IS: ";
450  PRINT PEEK(254)
```

The program begins by calling the CHARACTER subroutine to obtain two ASCII based hex characters (lines 310 to 390) and places them in locations 251 ($FB) and 252 ($FC). The high nibble character is converted first by calling the CHECK subroutine (lines 230 to 290). If the ASCII based character byte is in the range 0–9 the high nibble is masked off (line 250), otherwise 55 is subtracted from it (line 280). This has the same effect as masking off the high nibble and adding nine!

On returning from the CHECK subroutine the result, now held in the low four bits, is shifted left into the high nibble of the accumulator (lines 120 to 150) and saved for future reference (line 160).

A similar procedure is used to convert the low ASCII based character, but on return from the CHECK subroutine the resultant binary is logically ORed with the previous result (line 190) to produce the final value. This is then stored in location 254 ($FD).

This program could be improved in a number of ways; for instance, the ASCII characters are not echoed to the screen, nor are there any checks to ensure that only legal hex values are entered. You might like to add these extra facilities yourself?

BINARY TO HEX CONVERSION

To convert an eight bit binary number into its ASCII hex equivalent characters, the process described above is reversed. However, because characters are printed on the screen from left to right we must, in this instance, deal with the high nibble of the byte first. Program 42 requests a number for conversion (lines 300–370) and holds it in the accumulator. It is then pushed onto the stack (line 90), and the high nibble is shifted four times to move it into the low nibble position (lines 100–130). The subroutine FIRST does the conversion. After ensuring that no high bits are set (line 170) the binary value is tested to see if it's in the range 0–9 (line 180). If it is not (and is therefore in the range A–F), 7 is added to the accumulator (line 200—6 by the command plus 1 from the Carry flag). Line 220 performs the conversion by adding $30, which effectively sets bits 4 and 5. After printing the ASCII character (line 230) control returns back to line 150, where the original binary value is pulled off the stack in readiness for the low nibble (line 170) to be converted into the appropriate ASCII character.

Program 42

```
10  REM * * PRINT ACCUMULATOR AS HEX NUMBER * *
20  CODE = 49152
30  FOR LOOP = 0 TO 21
40    READ BYTE
50    POKE CODE + LOOP, BYTE
60  NEXT LOOP
```

```
70
80  REM * * M/C DATA * *
90  DATA 72          : REM $48            — PHA
100 DATA 74          : REM $4A            — LSR A
110 DATA 74            REM $4A            — LSR A
120 DATA 74            REM $4A            — LSR A
130 DATA 74            REM $4A            — LSR A
140 DATA 32,9,192      REM $20, $09, $C0  — JSR FIRST
150 DATA 104         : REM $68            — PLA
160 REM * * FIRST SUBROUTINE : $C009 * *
170 DATA 41,15       : REM $29, $0F       — AND #$0F
180 DATA 201,10        REM $C9, $0A       — CMP #$0A
190 DATA 144,2         REM $90, $02       — BCC OVER
200 DATA 105,6       : REM $69, $06       — ADC #$06
210                    REM OVER
220 DATA 105,48      : REM $69, $30       — ADC #$30
230 DATA 76,210,255    REM $4C, $D2, $FF  — JMP $FFD2
240
250 REM * * DEMO PROGRAM * *
260 REM LDA $FB : JMP $C000
270 POKE 828, 165 : POKE 829, 251
280 POKE 830, 76 : POKE 831, 0 : POKE 832, 192
290 PRINT CHR$(147)
300 PRINT "HIT A KEY AND ITS HEX VALUE IN "
310 PRINT "ASCII WILL BE DISPLAYED"
320 GET A$
330 IF A$=" " THEN GOTO 320
340 A = ASC(A$)
350 POKE 251, A
360 REM * * CALL LINK ROUTINE—LINES 270 and 280 * *
370 SYS 828
380 REM * * CALL 'SYS CODE' TO USE DIRECTLY * *
```

Program 42 is demonstrated by pressing any of the alphanumeric keys—it then prints their ASCII hexadecimal value.

OUTPUT ASCII STRING

This utility subroutine—Program 43—enables ASCII character strings to be stored within the body of machine code programs ready for printing on to the screen. It has two advantages over the normal absolute indexing approach. Firstly, it is inserted into the program at the point it is needed and secondly, it calculates its own address and is therefore fully relocatable.

Program 43

```
10  REM * * ASCII STRING OUTPUT ROUTINE * *
20  CODE = 49152
30  FOR LOOP = 0 TO 26
40    READ BYTE
50    POKE CODE  + LOOP, BYTE
60  NEXT LOOP
70
80  REM * * M/C DATA * *
90  DATA 104          : REM $68            — PLA
100 DATA 133,251      : REM $85, $FB       — STA $FB
120 DATA 104            REM $68            — PLA
130 DATA 133,252        REM $85, $FC       — STA $FC
140                     REM REPEAT
150 DATA 160,0          REM $A0, $00       — LDY #$00
160 DATA 230,251        REM $E6, $FB       — INC $FB
170 DATA 208,2          REM $D0, $02       — BNE CLEAR
180 DATA 230,252        REM $E6, $FC       — INC $FC
190                     REM CLEAR
200 DATA 177,251      : REM $B1, $FB       — LDA ($FB), Y
210 DATA 48,6         : REM $30, $06       — BMI FINISH
220 DATA 32,210,255   : REM $20, $D2, $FF  — JSR $FFD2
230 DATA 76,6,192     : REM $4C, $06, $C0  — JMP REPEAT
240                     REM FINISH
250 DATA 108,251,0    : REM $6C, $FB, $00  — JMP ($FB)
260
270 REM * * DEMO ROUTINE * *
280 REM * * LOCATED AT $C200 * *
290 DEMO = 49664
300 FOR LOOP = 0 TO 22
310   READ BYTE
320   POKE DEMO + LOOP, BYTE
330 NEXT LOOP
340
350 DATA 169,147      : REM $A9, $93       — LDA #$93
360 DATA 32,210,255   : REM $20, $D2, $FF  — JSR $FFD2
370 DATA 32,0,192     : REM $20, $00, $C0  — JSR OUTPUT
380 REM * * NOW STORE ASCII CODES FOR PRINTING * *
390 DATA  67, 79, 77, 77, 79, 68, 79, 82, 69, 32, 54, 52,  13
400 REM    C,  O,  M,  M,  O,  D,  O,  R,  E,   ,  6,  4,<CR>
```

```
410 DATA 234          : REM $EA          — NOP
420 DATA 96           : REM $60          — RTS
430 SYS DEMO
```

The main ASCII output routine is between lines 90 and 250, a short demonstration program is included in lines 350 to 420. The demo program begins by clearing the screen (lines 350 and 360), then the OUTPUT routine located at $C000 is called. Immediately following this call the ASCII text for output is POKEd into memory. The end of the string is marked by a negative byte—one that has its most significant bit set. NOP is ideal for this because it doesn't do anything (line 410)!

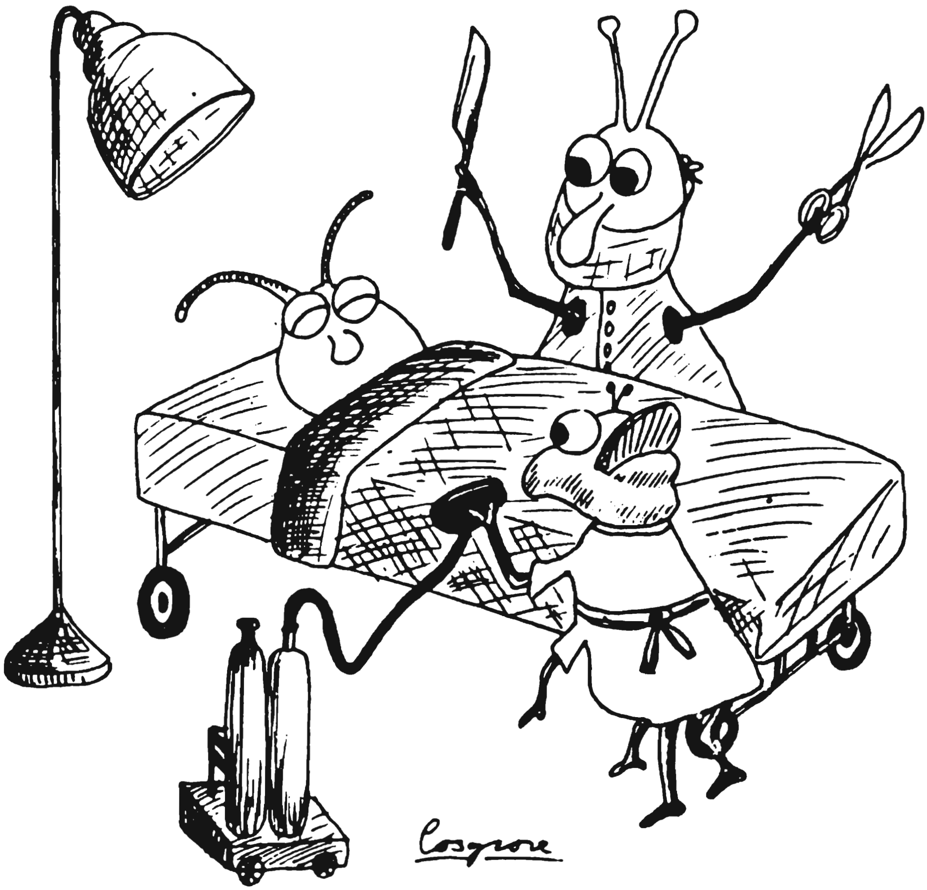
The ASCII print routine, which is just 27 bytes long, begins by pulling the RTS address (from the calling subroutine) off the stack and placing it into two zero page locations, 251 ($FB) and 252 ($FC).

Because the string immediately follows the CODE subroutine call (see Figure 23.1), post-indexed indirect addressing can be used to load the first string character into the accumulator (line 200). Line 210 tests to see if the string-terminating negative byte has been reached. If not, the character is printed (line 220). A JMP back to REPEAT is implemented (line 230) and the zero page address incremented (lines 160–180) so that the next string character can be sought out. Once the negative byte is encountered and the test of line 210 succeeds, an indirect jump (line 250) via the zero page address will return control to the calling machine code program.

Address		Hex	Mnemonic/character
49664	$C000	A9	LDA#
49665	$C001	93	147
49666	$C002	20	JSR
49667	$C003	D2	$FFD2
49668	$C004	FF	
49669	$C005	20	JSR
49670	$C006	00	$C000
49671	$C007	C0	
49672	$C008	43	C
49673	$C009	4F	O
49674	$C00A	4D	M
49675	$C00B	4D	M
49676	$C00C	4F	O
49677	$C00D	44	D
49678	$C00E	4F	O
49679	$C00F	52	R
49680	$C010	45	E
49681	$C011	20	
49682	$C012	36	6
49683	$C013	34	4
49684	$C014	0D	<CR>
49685	$C015	EA	NOP
49686	$C016	60	RTS

Figure 23.1 Memory layout of part of Program 43.

Appendices



I The Screen

The character set can be displayed on the screen in two different ways:

1. By printing the ASCII code.
2. By storing the screen code into screen memory and setting the colour memory.

The screen and ASCII codes are listed in the *Manual,* Appendix E.

To print an ASCII code on to the screen, first load the ASCII code into the accumulator and then call the Kernal CHROUT routine at $FFD2. For example to print an 'A' use:

```
LDA #65          \ ASCII code for A
JSR $FFD2        \ print it
```

The print position can be specified by first calling the Kernal PLOT routine.

Using screen codes is slightly more involved. First the screen code must be placed into the relevant screen memory position, and then the corresponding location in the colour memory must be POKEd with the specified colour code to 'turn on' the print colour. For example, to display a blue 'A' midway down the left-hand side of the screen the following can be used:

```
LDA #1           \ POKE code for A
STA 1424         \ store in screen memory
LDX #6           \ code for blue
STX 55696        \ store in colour memory to show blue
                   letter A
```

Figures A1.1 and A1.2 show the screen and colour memory maps.

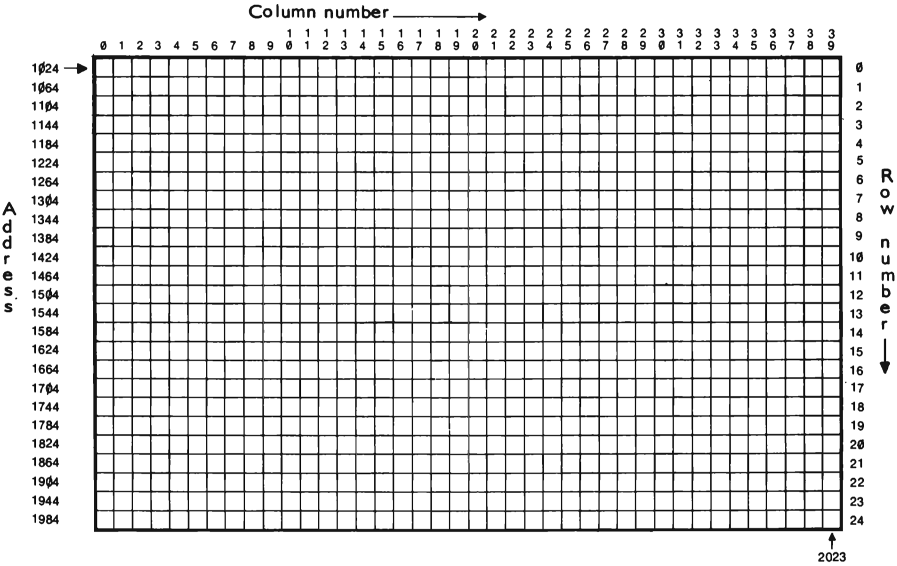


Figure A1.1 The screen memory map.

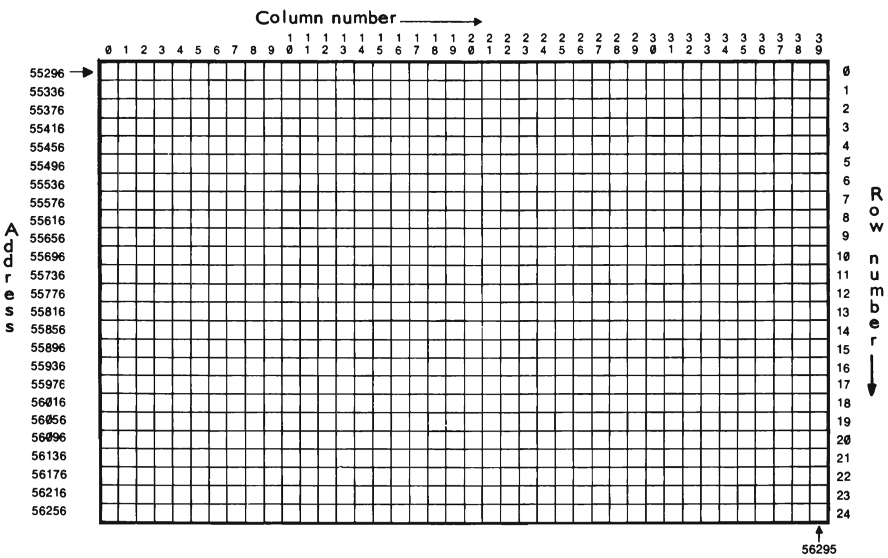


Figure A1.2 The colour memory map.

2 The 6510

So far throughout this book we have been concerned with the software aspects of the Commodore's 6510, or in other words, how to program it! We could not really finish without having a glimpse at its hardware or physical features. For example, just how is it organized internally and how does it transfer data to and fro? While it is not absolutely vital to understand these features, an understanding of its design will enhance your new found knowledge.

Figure A2.1 shows a simplified block diagram of the 6510's design or *architecture* as it is more commonly called. If you study it many of the features will be readily recognizable. There are a few exceptions though, including three buses, the address bus, the data bus, and the control bus. You may well be wondering just what is meant by bus? It is not, as you may have thought, a number 19 bound for Highbury Barn—it's simply a collective term for a series of wires—or *tracks* as they are called on a *Printed Circuit Board* (PCB for short)—onto which a 1 or a 0 can be placed electronically.

By placing a series of 1s and 0s onto the eight lines of the data bus, a byte of information may be transferred to or from the address specified by the binary value present at that instant in time on the 16 lines of the address bus.

The control bus lines are responsible for carrying the numerous synchronization signals that are required for the Commodore to operate.

EXECUTING INSTRUCTIONS

We can now examine just how the 6510 fetches, interprets and executes each instruction. Firstly, the 6510 must locate and read the next instruction of the machine code program. It does this by placing the current contents of the Program Counter onto the address bus and simultaneously placing a read signal on the appropriate control bus line. Almost instantaneously the instruction, or more correctly the byte that constitutes the instruction, is placed onto the data bus. The 6510 then reads the contents of the data bus into a special internal, eight bit register, known as the Instruction Register (IR for short), which is used exclusively by the 6510 to hold data waiting for processing. Once in the IR, the Control Unit interprets the instruction and then generates the various internal and external signals required to execute the instruction. For example, if the data byte fetched was $A5, the 6510 would interpet this as LDA zero page, and would fetch the next byte of data and interpret this as the address at which the data to be placed into the accumulator is located. Each one of these operations would be performed in a manner similar to that already described.

Obviously instructions and data must be fetched in the correct sequence. To enable this to happen the Program Counter is provided with an automatic incrementing device. Each time the Program Counter's contents are placed onto the address bus the incrementer adds one to its contents, thus ensuring bytes are fetched and stored in the correct order.

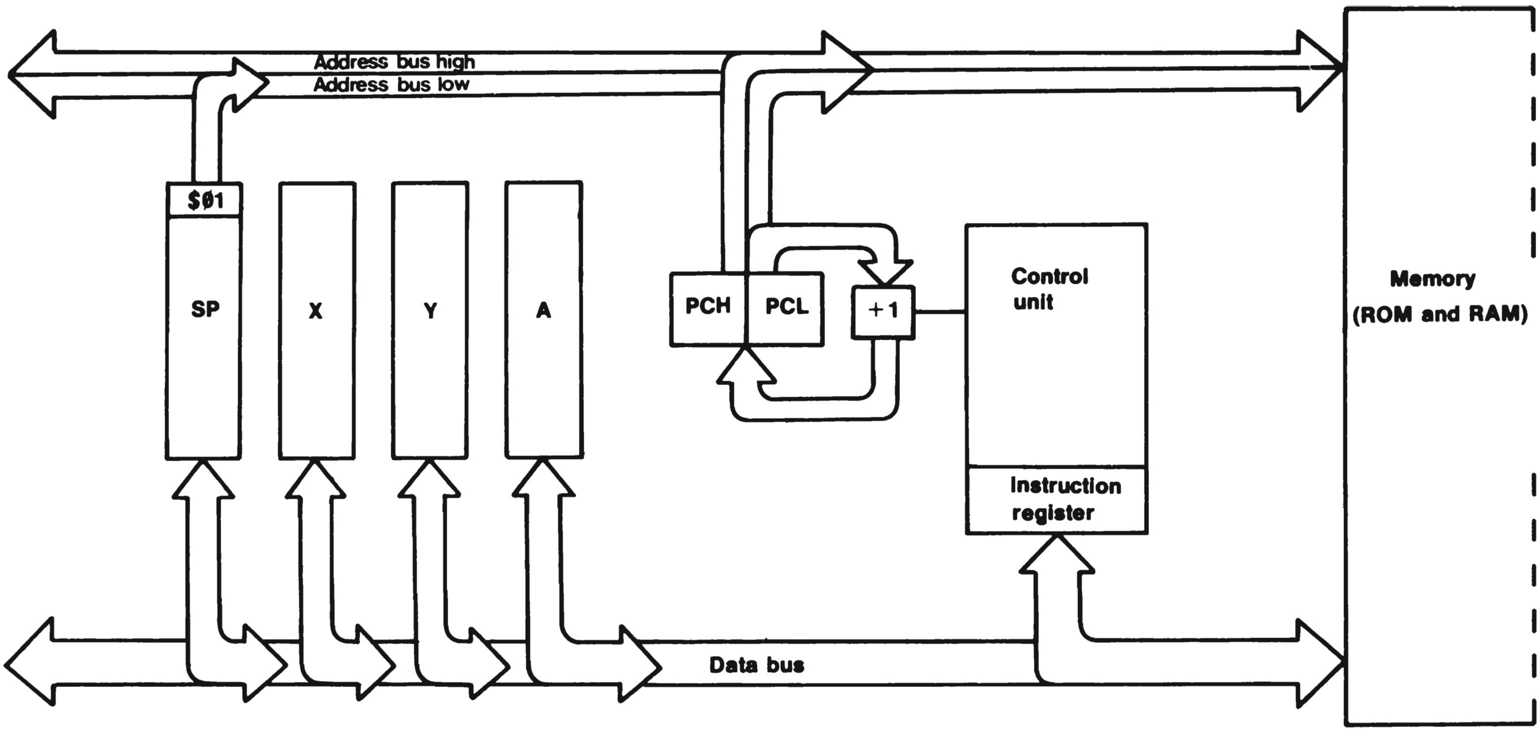


Figure A2.1 The 651Ø—block diagram.

The 6510 also contains two further registers that I haven't mentioned up until now. These are associated with the input/output port of the 6510 and are called the *Data Direction register* and the *Data register*. They are responsible for memory management in the Commodore 64 and actually appear on the memory map as the very first two locations in zero page.

As its name suggests, the Data Direction register ($0000) determines whether data is to be input or output from the Data register. If a bit is set then that particular line is configured for input, if the bit is clear it is configured for output. The normal Data Direction register configuration is xx101111 where the xx means 'don't care'!

Only the first six Data register lines are used and their purposes are as follows:

Bit 0	LORAM signal—if this bit is low then the BASIC ROM is switched out.
Bit 1	HIRAM signal—if this bit is low then the Kernal ROM is switched out.
Bit 2	CHAREN signal.
Bit 3	Tape data output line.
Bit 4	Tape switch sense—high if switch closed.
Bit 5	Tape motor control—high if off.
Bits 6–7	Not used.

3 The Instruction Set

This section contains a full description of each of the 56 instructions that the 6502 is provided with. For ease of reference, the instructions are arranged in alphabetical order by mnemonic, and each description is broken down into the following six sections:

Introduction A brief one or two line description of the instruction's function.

Table This details the addressing modes available with the instruction, and lists the various opcodes, the total number of memory bytes required by each addressing mode, and finally the number of cycles that particular addressing mode takes to complete.

Status Shows the effect the execution of the instruction has on the Status register. The following codes are employed:

- * The flag is affected by the instruction but bits are undefined, being dependent on the byte's contents
- 1 The flag is set by the instruction
- 0 The flag is cleared by the instr

If no code is indicated the flag remains unaltered by the instruction.

Operation A brief description of how the instruction operates together with details of its effect on the Status register.

Applications Some hints and tips on the sort of applications the instruction might be used for.

References A list of the page numbers giving further information about the instruction.

ADC

Add memory to accumulator with carry.

Addressing	Opcode Decimal	Opcode Hex	Bytes	Cycles
ADC #immediate	105	$69	2	2
ADC zero page	101	$65	2	3
ADC zero page, X	117	$75	2	4
ADC absolute	109	$6D	3	4
ADC absolute, X	125	$7D	4	4/5
ADC absolute, Y	121	$79	3	4/5
ADC (zero page, X)	97	$61	2	6
ADC (zero page), Y	113	$71	2	5/6

N	V	—	B	D	I	Z	C
*	*					*	*

Operation Adds the contents of the specified memory location to the current contents of the accumulator. If the Carry flag is set this is added to the result which is then stored in the accumulator. If the result is greater than $FF (255) the Carry flag is set. If the result is equal to zero the Zero flag is set. The contents of bit 7 of the accumulator are copied into the Status register. If overflow occurred from bit 6 to bit 7 the Overflow flag is set.

Applications Allows single, double and multibyte numbers to be added together. Overflow from one byte to another is provided by the Carry flag which is included in the addition.

References Page: 41

AND

Logical AND of memory location with accumulator.

Addressing	Opcode Decimal	Opcode Hex	Bytes	Cycles
AND #immediate	41	$29	2	2
AND zero page	37	$25	2	3
AND zero page, X	53	$35	2	4
AND absolute	45	$2D	3	4
AND absolute, X	61	$3D	3	4/5
AND absolute, Y	57	$39	3	4/5
AND (zero page, X)	33	$21	2	6
AND (zero page), Y	49	$31	2	5

N	V	—	B	D	I	Z	C
*						*	

Operation Logically ANDs the corresponding bits of the accumulator with the specified value or contents of memory location. The result of the operation is stored in the accumulator but memory contents remain unaltered. If the result of the AND is Ø, the Zero flag is set. If the result leaves bit 7 set, the Negative flag is set. Otherwise both flags are cleared.

Applications Used to 'mask off' the unwanted bits of the accumulator.

```
AND #$FØ        \ masks off lower nibble, 1111ØØØØ
AND #$ØF        \ masks off higher nibble, ØØØØ1111
```

References Page: 16

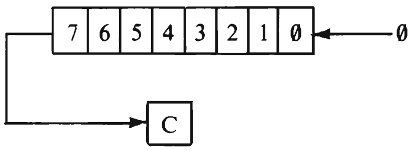
ASL

Shift contents of accumulator or memory left by one bit.

Addressing	Opcode Decimal	Opcode Hex	Bytes	Cycles
ASL accumulator	10	$0A	1	2
ASL zero page	6	$06	2	5
ASL zero page, X	22	$16	2	6
ASL absolute	14	$0E	3	6
ASL absolute, X	30	$1E	3	7

N	V	—	B	D	I	Z	C
*						*	*

Operation Shuffles the bits in a specified location one bit left. Bit 7 moves into the carry, and a zero is placed into the vacated bit 0.



The Carry flag is set if bit 7 contained a 1 before the shift, and cleared if it contained 0. The Negative flag is set if bit 6 previously contained a 1. The Zero flag is set if the location holds $00 after the shift. (For this to occur it must previously have contained either $00 or $80.

Applications Multiplies the byte by two. Can be used to shift low nibble of byte into high nibble.

References Page: 78

BCC

Branch if the Carry flag is clear (C = 0).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
BCC relative	144	$90	2	2/3/4

N	V	—	B	D	I	Z	C

Operation If the Carry flag is clear (C = 0) the byte following the instruction is interpreted as a two's complement number and is added to the current contents of the Program Counter. This gives the new address from which the program will now execute, allowing a branch of either 126 bytes back or 129 bytes forward. If the Carry flag is set (C = 1) the branch does not occur and the next byte is ignored by the 6510.

Applications The Carry flag is conditioned by a number of instructions such as ADC, SBC, CMP, CPX and CPY, and a branch will occur if any of these result in clearing the flag. A 'forced' branch can be implemented using:

```
CLC             \ C = 0
BCC value       \ 'jump'
```

References Pages: 32, 64

BCS

Branch if the Carry flag is set (C = 1).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
BCS relative	176	$B0	2	2/3/4

N	V	—	B	D	I	Z	C

Operation If the Carry flag is set (C = 1) the byte following the instruction is interpreted as a two's complement number and is added to the current contents of the Program Counter; this gives the new address from which the program will now execute, allowing a branch of either 126 bytes back or 129 bytes forward. If the Carry flag is clear (C = 0) the branch does not occur and the next byte is ignored by the 6510.

Applications As with BCC but the branch will only take place if an operation results in the Carry flag being set. A 'forced' branch can be implemented with:

```
SEC             \ C = 1
BCS set         \ 'jump'
```

References Page: 32

BEQ

Branch if the Zero flag is set (Z = 1).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
BEQ relative	240	$F0	2	2/3/4

N	V	—	B	D	I	Z	C

Operation If the Zero flag is set (Z = 1) the byte following the instruction is interpreted as a two's complement number and is added to the current contents of the Program Counter; this gives the new program address from which the program will now execute, allowing a branch of either 126 bytes back or 129 bytes forward. If the Zero flag is clear (Z = 0) the branch does not occur and the next byte is ignored by the 6510.

Applications Used to cause a branch when the Zero flag is set. This happens when an operation results in zero (e.g. LDA #0). The BEQ command is used frequently after a comparison instruction, for example:

```
CMP #ASC"?"
BEQ Questionmark
```

If the comparison succeeds the Zero flag is set therefore BEQ will work.

References Page: 64

BIT

Test memory bits.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
BIT zero page	36	$24	2	3
BIT absolute	44	$2C	3	4

N	V	—	B	D	I	Z	C
*	*					*	

Operation The BIT operation affects only the Status register, the accumulator and the specified memory location are unaltered. Bit 7 and bit 6 of the memory byte are copied directly into N and V respectively. The Zero flag is conditioned after a logical bitwise AND between the accumulator and the memory byte. If accumulator AND memory results in zero then Z = 1, otherwise Z = 0.

Applications Often used in conjunction with BPL/BMI or BVS/BVC to test bits 7 and 6 of a memory location and to cause a branch depending on their condition.

References Page: 85

BMI

Branch if the Negative flag is set (N = 1).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
BMI relative	48	$30	2	2/3/4

N	V	—	B	D	I	Z	C

Operation If the Negative flag is set (N = 1) the byte following the instruction is interpreted as a two's complement number and is added to the current contents of the Program Counter; this gives the new address from which the program will now execute, allowing a branch of either 126 bytes back or 129 bytes forward. If the Negative flag is clear (N = 0) the branch does not occur and the next byte is ignored by the 6510.

Applications Generally after an operation has been performed (i.e. LDA, LDX etc.) the most significant bit of the register is copied into the Negative flag position. If it is set then a branch will occur using BMI. The 'minus' part of the mnemonic denotes this instruction's importance when using signed arithmetic—where bit 7 is used to denote the sign of a number in two's complement form.

References Pages: 31, 64

BNE

Branch if the Zero flag is clear (Z = 0).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
BNE relative	208	$D0	2	2/3/4

N	V	—	B	D	I	Z	C

Operation If the Zero flag is clear (Z = 0) the byte following the instruction is interpreted as a two's complement number and is added to the current contents of the Program Counter; this gives the new address from which the program will now execute, allowing a branch of either 126 bytes back or 129 bytes forward. If the Zero flag is set (Z = 1) the branch does not occur and the next byte is ignored by the 6510.

Applications Used to cause a branch when the Zero flag is clear. It's often used, in conjunction with a decrementing counter, as a loop controlling command.

```
DEX
BNE AGAIN
```

will continue branching back to AGAIN until X = 0 and the Zero flag is set.

References Page: 64

BPL

Branch if the Negative flag is clear (N = 0).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
BPL relative	16	$10	2	3/4/5

N	V	—	B	D	I	Z	C

Operation If the Negative flag is clear (N = 0) the byte following the instruction is interpreted as a two's complement number and is added to the current contents of the Program Counter; this gives the new address from which the program will now execute, allowing a branch of either 126 bytes back or 129 bytes forward. If the Negative flag is set (N = 1) the branch does not occur and the next byte is ignored by the 6510.

Applications Generally after an operation has been performed (i.e. LDA, ROL, CPX etc.) the most significant bit of the register is copied into the Negative flag position. If it is clear then a branch will occur if BPL is used. The 'plus' part of the mnemonic denotes the instruction's importance when using signed arithmetic, where bit 7 is used to indicate the sign of a number in two's complement form. If a decrementing counter is being used in a loop this branch instruction allows the loop to execute when the counter reaches zero.

```
DEX
BPL again
```

This loop will finish when X is decremented from 0 to $FF because $FF = 1111 1111 binary, where bit 7 is set.

References Pages: 31, 64

BRK

Software forced BREAK.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
BRK implied	00	$00	1	7

N	V	—	B	D	I	Z	C
			1				

Operation The Program Counter address plus one is pushed onto the stack, followed by the contents of the Status register. The Break flag is set and the Commodore passes control to the BRK servicing routine at $FFFE.

Applications Used as a software interrupt.

References Page: 130

BVC

Branch if the Overflow flag is clear (V = 0).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
BVC relative	80	$50	2	2/3/4

N V — B D I Z C

Operation If the Overflow flag is clear (V = 0) the byte following the instruction is interpreted as a two's complement number and added to the current contents of the Program Counter. This gives the new address from which the program will now execute. This allows a branch of either 126 bytes back or 129 bytes forward. If the Overflow flag is set (V = 1) the branch does not take place and the next byte is ignored by the 6510.

Applications Used to detect an overflow from bit 6 into bit 7 (i.e. a carry from bit 6 to bit 7) when using signed arithmetic. When using signed arithmetic two numbers of opposite sign *cannot* overflow, however numbers of the same sign *can* overflow. For example:

```
    01001111     ($4F)
+   01000000     ($40)
    --------
    10001111     (-$71)
    ↑
    └─Overflow from bit 6 to bit 7
```

The result is now negative which is, of course, absurd! Similarly adding two large negative numbers can produce a positive result. In fact overflow can occur in the following situations:

1. Adding large positive numbers.
2. Adding large negative numbers.
3. Subtracting a large negative number from a large positive number.
4. Subtracting a large positive number from a large negative number.

The Overflow flag is used to signal this overflow from bit 6 to bit 7 and therefore, in signed arithmetic, a change in sign. If it is clear no overflow has occurred and BVC will cause a branch.

A 'forced' branch may be implemented using:

```
CLV              \ clear V
BVC Forced       \ 'jump'
```

References Page: 64

BVS

Branch if the Overflow flag is set (V = 1).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
BVS relative	112	$70	2	2/3/4

N	V	—	B	D	I	Z	C

Operation If the Overflow flag is set (V = 1) the byte following the instruction is interpreted as a two's complement number and added to the current contents of the Program Counter. This gives the new address from which the program will now execute, allowing a branch of either 126 bytes back or 129 bytes forward. If the Overflow flag is clear (V = 0) the branch does not occur and the next byte is ignored by the 6510.

Applications Used to cause a branch if the sign of a number has been changed. In most instances this will only matter if signed arithmetic is being employed. See BVC for more details.

References Page: 64

CLC

Clear the Carry flag (C = 0).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
CLC implied	24	$18	1	2

N	V	—	B	D	I	Z	C
							0

Operation The Carry flag is cleared by setting it to zero.

Applications Should always be used before adding two numbers together as the Carry flag's contents are taken into account by ADC. A 'forced' branch may be implemented with:

```
CLC             \ Clear C
BCC clear       \ and 'jump'
```

References Pages: 32, 40

CLD

Clear the Decimal flag (D = 0).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
CLD implied	216	$D8	1	2

N	V	—	B	D	I	Z	C
				0			

Operation The Decimal flag is cleared by setting it to zero.

Applications Used to make 6510 work in normal hexademical mode.

References Page: 47

CLI

Clear the Interrupt flag (I = 0).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
CLI implied	88	$58	1	2

N	V	—	B	D	I	Z	C
					0		

Operation The Interrupt flag is cleared by setting it to zero.

Applications Causes any interrupts on the IRQ line to be processed immediately after completion of current instruction.

References Page: 129

CLV

Clear the Overflow flag (V = Ø).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
CLV implied	184	$B8	1	2

N	V	—	B	D	I	Z	C
	Ø						

Operation The Overflow flag is cleared by setting it to zero.

Applications Used to clear the Overflow flag after an overflow from bit 6 to bit 7. In most instances this is only important if signed arithmetic is being used.

CMP

Compare contents of memory with contents of the accumulator.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
CMP #immediate	201	$C9	2	2
CMP zero page	197	$C5	2	3
CMP zero page, X	213	$D5	2	4
CMP absolute	205	$CD	3	4
CMP absolute, X	221	$DD	3	4/5
CMP absolute, Y	217	$D9	3	4/5
CMP (zero page, X)	193	$C1	2	6
CMP (zero page), Y	209	$D1	2	5/6

N	V	—	B	D	I	Z	C
*						*	*

Operation The contents of the specified memory location (or immediate value) are subtracted from the contents of the accumulator. The contents of the memory location and accumulator are *NOT* altered, but the Negative, Zero and Carry flags are conditioned according to the result of the subtraction. To perform this subtraction, the 6510 first sets the Carry flag and then adds the two's complement value of the memory location's contents to the accumulator's contents. If both values are equal (memory = accumulator) the Zero flag is set and the Carry flag remains set. If the contents of memory are less than the accumulator (memory $<$ accumulator) the Zero flag is cleared and the Carry flag set. If memory contents are greater than the accumulator (memory $>$ accumulator) then both the Zero flag and Carry flag are cleared. If unsigned binary is being used the Negative flag is also set. If signed binary is being used the Overflow flag should be checked in conjunction with the Negative flag to test for a 'true' negative result.

Applications Should be used to test for intermediate values that cannot be tested directly from the Status register. For example:

```
CMP #00
BEQ AWAY
```

is a waste of two bytes, as the Zero flag will be set if the accumulator contains $00, therefore all that is needed is : BEQ AWAY. To test for a particular key, the following CMP might be used:

```
JSR GETIN          \ get key
CMP #ASC"Y"        \ is it Y key?
BEQ YES
```

References Page: 64

CPX

Compare contents of memory with contents of the X register.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
CPX #immediate	224	$EØ	2	2
CPX zero page	228	$E4	2	3
CPX absolute	236	$EC	3	4

N	V	—	B	D	I	Z	C
*						*	*

Operation The contents of the specified memory location (or immediate value) are subtracted from the contents of the X register. The contents of the memory location and X register are *NOT* altered, instead the Negative, Zero and Carry flags are conditioned according to the result of the subtraction. To perform this subtraction the 651Ø first sets the Carry flag and then adds the two's complement value of the memory location to the contents of the X register. If both values are equal (memory = X register) the Zero flag is set and the Carry flag remains set. If the contents of memory are less than the X register (memory < X register) the Zero flag is cleared but the Carry flag remains set. If memory contents are greater than the X register (memory > X register) then both Zero and Carry flags are cleared. If unsigned binary is being used then the Negative flag is set.

Applications Should be used to test for intermediate values which cannot be tested directly from the Status register. For example, to test the X register's contents during use as a loop counter try:

```
        LDX #22Ø      \ load X with 22Ø
AGAIN   DEX           \ decrement X
        CPX #87       \ has X reached 87?
        BNE AGAIN     \ no, go again
```

References Page: 64

CPY

Compare contents of memory with contents of the Y register.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
CPY #immediate	192	$CØ	2	2
CPY zero page	196	$C4	2	3
CPY absolute	2Ø4	$CC	3	4

N	V	—	B	D	I	Z	C
*						*	*

Operation The contents of the specified memory location (or immediate value) are subtracted from the contents of the Y register. The contents of the memory location and Y register are *NOT* altered, instead the Negative, Zero and Carry flags are conditioned according to the result of the subtraction. To perform this subtraction the 651Ø first sets the Carry flag and then adds the two's complement value of the memory location to the contents of the Y register. If both values are equal (memory = Y register) the Zero flag is set and the Carry flag remains set. If the contents of memory are less than the Y register (memory < Y register) the Zero flag is cleared but the Carry flag remains set. If memory contents are greater than the Y register (memory > Y register) then both Zero and Carry flags are cleared. If unsigned binary is being used then the Negative flag is set.

Applications Should be used to test for intermediate values which cannot be tested directly from the Status register. For example, to test the Y register's contents during use as a loop counter try:

```
        LDY #22Ø        \ load Y with 22Ø
AGAIN   DEY             \ decrement Y
        CPY #87         \ has Y reached 87?
        BNE AGAIN       \ no, go again
```

References Page: 64

DEC

Decrement memory contents by one.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
DEC zero page	198	$C6	2	5
DEC zero page, X	214	$D6	2	6
DEC absolute	206	$CE	3	6
DEC absolute, X	222	$DE	3	7

N	V	—	B	D	I	Z	C
*						*	

Operation The byte at the address specified is decremented by one (MEMORY = MEMORY −1). If the result of the operation is zero the Zero flag will be set. Bit 7 of the byte is copied into the Negative flag.

Applications Used to subtract one from a counter stored in memory.

References Page: 62

DEX

Decrement contents of X register by one.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
DEX implied	2Ø2	$CA	1	2

N	V	—	B	D	I	Z	C
*						*	

Operation One is subtracted from the value currently held in the X register (X = X − 1). If the result of the operation is zero the Zero flag will be set. Bit 7 is copied into the Negative flag (N = Ø if X < $8Ø; N = 1 if X > $7F). The Carry flag is not affected by the instruction.

Applications Used with indexed addressing when the X register acts as an offset from a base address, allowing a sequential set of bytes to be accessed. Invariably used to decrement the X register when being used as a loop counter, branching until X = Ø (Z = 1).

References Page: 62

DEY

Decrement contents of Y register by one.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
DEY implied	136	$88	1	2

N	V	—	B	D	Z	C
*					*	

Operation One is subtracted from the value currently held in the Y register (Y = Y − 1). If the result of the operation is zero the Zero flag is set. Bit 7 is copied into the Negative flag (N = Ø if Y < $8Ø;N = 1 if Y > $7F). The Carry flag is not affected by the instruction.

Applications Used with indexed addressing when the Y register acts as an offset from a base address allowing a sequential set of bytes to be accessed. Invariably used to decrement the Y register when being used as a loop counter, branching until Y = Ø (Z = 1).

References Page: 62

EOR

Accumulator exclusively ORed with memory.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
EOR #immediate	73	$49	2	2
EOR zero page	69	$45	2	3
EOR zero page, X	85	$55	2	4/5
EOR absolute	77	$4D	3	4
EOR absolute, X	93	$5D	3	4/5
EOR absolute, Y	89	$59	3	4/5
EOR (zero page, X)	65	$41	2	6
EOR (zero page), Y	81	$51	2	5/6

N	V	—	B	D	Z	C
*					*	

Operation Performs a bitwise exclusive OR between the corresponding bits in the accumulator and the specified memory byte. If the result, which is stored in the accumulator, is zero the Zero flag is set. Bit 7 is copied into the Negative flag.

Applications Used to complement or invert a data byte.

References Page: 17

INC

Increment memory contents by one.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
INC zero page	230	$E6	2	5
INC zero page, X	246	$F6	2	6
INC absolute	238	$EE	3	6
INC absolute, X	254	$FE	3	7

N	V	—	B	D	I	Z	C
*						*	

Operation The byte at the address specified is incremented by one. If the address holds zero after the operation the Zero flag is set. Bit 7 of the byte is copied into the Negative flag.

Applications Add one to a counter stored in memory.

References Page: 62

INX

Increment contents of X register by one.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
INX implied	232	$E8	1	2

N	V	—	B	D	I	Z	C
*						*	

Operation One is added to the value currently in the X register (X = X + 1). If the result of the operation is zero the Zero flag will be set. Bit 7 is copied into the Negative flag (N = Ø if X < $8Ø ; N = 1 if X > $7F). The Carry flag is not affected by the instruction.

Applications Used with indexed addressing when the X register acts as an offset from a base address, and allows a sequential set of bytes to be accessed. Often used as a counter to control the number of times a loop of instructions is executed.

References Page: 62

INY

Increment contents of Y register by one.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
INY implied	2ØØ	$C8	1	2

N	V	—	B	D	I	Z	C
*						*	

Operation One is added to the value currently held in the Y register (Y = Y + 1). If the result of the operation is zero the Zero flag will be set. Bit 7 is copied into the Negative flag. The Carry flag is not affected.

Applications Used with indexed addressing when the Y register acts as an offset from a base address, allowing a sequential set of bytes to be accessed. Often used as a counter to control the number of times a loop is executed.

References Page: 62

JMP

Jump to a new location.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
JMP absolute	76	$4C	3	3
JMP (indirect)	108	$6C	3	3

N V — B D I Z C

Operation In an absolute JMP the two bytes following the instruction are placed into the Program Counter. In an indirect jump the two bytes located at the two byte address following the instruction are loaded into the Program Counter.

Applications Transfers control, unconditionally, to another part of a program stored anywhere in memory.

References Pages: 54, 55, 76

JSR

Jump, save return address.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
JSR absolute	32	$20	3	6

N V — B D I Z C

Operation Acts as a subroutine call, transferring program control to another part of memory until an RTS is encountered. The current contents of the Program Counter plus two are pushed onto the stack. The Stack Pointer is incremented twice. The absolute address following the instruction is placed into the Program Counter and program execution continues from this new address.

Applications Allows large repetitive sections of programs to be entered once, out of the way of the main program, and called as subroutines as often as required.

References Page: 72

LDA

Load the accumulator with the specified byte.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
LDA #immediate	169	$A9	2	2
LDA zero page	165	$A5	2	3
LDA zero page, X	181	$B5	2	4
LDA absolute	173	$AD	3	4
LDA absolute, X	189	$BD	3	4/5
LDA absolute, Y	185	$B9	3	4/5
LDA (zero page, X)	161	$A1	2	6
LDA (zero page), Y	177	$B1	2	5/6

N	V	—	B	D	I	Z	C
*						*	

Operation Places the value immediately following the instruction, or the contents of the location specified after the instruction, into the accumulator. If the value loaded is zero then the Zero flag is set. Bit 7 is copied into the Negative flag position.

Applications Probably the most frequently used instruction, it allows for general data movement and facilitates all logical and arithmetic operations.

References Page: 36

LDX

Load the X register with the specified byte.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
LDX #immediate	162	$A2	2	2
LDX zero page	166	$A6	2	3
LDX zero page, Y	182	$B6	2	4
LDX absolute	174	$AE	3	4
LDX absolute, Y	190	$BE	3	4/5

N	V	—	B	D	I	Z	C
*						*	

Operation Places the value immediately following the instruction, or the contents of the location specified after the instruction, into the X register. If the value loaded is zero then the Zero flag is set. Bit 7 is copied into the Negative flag position.

Applications General transfer of data for processing or storage. Also allows a loop counter to be set to its start value.

References Page: 36

LDY

Load the Y register with the specified byte.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
LDY #immediate	160	$A0	2	2
LDY zero page	164	$A4	2	3
LDY zero page, X	180	$B4	2	4
LDY absolute	172	$AC	3	4
LDY absolute, X	188	$BC	3	4/5

N	V	—	B	D	I	Z	C
*						*	

Operation Places the value immediately following the instruction, or the contents of the location specified after the instruction, into the Y register. If the value loaded is zero the Zero flag is set. Bit 7 is copied into the Negative flag.

Applications General transfer of data for processing or storage. Also allows a loop counter to be set to its start value.

References Page: 36

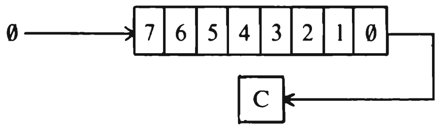
LSR

Logically shift the specified byte right one bit.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
LSR accumulator	74	$4A	1	2
LSR zero page	70	$46	2	5
LSR zero page, X	86	$56	2	6
LSR absolute	78	$4E	3	6
LSR absolute, X	94	$5E	3	7

N	V	—	B	D	I	Z	C
0						*	*

Operation Moves the contents of the specified byte right by one position, putting a 0 in bit 7 and bit 0 into the Carry flag.



The Negative flag is cleared, and the Carry flag is conditioned by the contents of bit 0. The Zero flag is set if the specified byte now holds zero (in which case it must previously have contained $00 or $01).

Applications Divides a byte value by two (if D = 0) with its remainder shifting into the Carry flag position. Can also be used to shift the high nibble of a byte into the low nibble.

References Pages: 79, 80

NOP

No operation.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
NOP implied	234	$EA	1	2

N	V	—	B	D	I	Z	C

Operation Does nothing except increment the Program Counter.

Applications Provides a two cycle delay.

References Page: 128

ORA

Logical OR of a specified byte with the accumulator.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
ORA #immediate	9	$Ø9	2	2
ORA zero page	5	$Ø5	2	3
ORA zero page, X	21	$15	2	4
ORA absolute	13	$ØD	3	4
ORA absolute, X	29	$1D	3	4/5
ORA absolute, Y	25	$19	3	4/5
ORA (zero page, X)	1	$Ø1	2	6
ORA (zero page), Y	17	$11	2	5

N	V	—	B	D	I	Z	C
*						*	

Operation Logically ORs the corresponding bits of the accumulator with the specified value, or contents of a memory location. The result of the operation is stored in the accumulator. If the result leaves bit 7 set the Negative flag is set, otherwise it is cleared.

Applications Used to 'force' certain bits to contain a one. For example:

```
ORA #$8Ø                    \ 1ØØØØØØØ binary
```

will ensure bit 7 is set.

References Pages: 50, 51, 53

PHA

Push the accumulator contents onto the 'top' of the stack.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
PHA implied	72	$48	1	3

N	V	—	B	D	I	Z	C

Operation The contents of the accumulator are copied into the position indicated by the Stack Pointer. The Stack Pointer is then decremented by one.

Applications Allows bytes of memory to be saved temporarily. The index registers can be saved by first transferring them to the accumulator; memory bytes are saved by first loading them into the accumulator. Bytes are recovered with PLA.

References Pages: 59, 60

PHP

Push the Status register's contents onto the top of the stack.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
PHP implied	8	$Ø8	1	3

N	V	—	B	D	I	Z	C

Operations The contents of the Status register are copied into the position indicated by the Stack Pointer. The Stack Pointer is then decremented by one.

Applications Allows the conditions of the flags to be saved, perhaps prior to a subroutine call, so that the same conditions can be restored with PLP on return.

References Pages: 59, 60

PLA

Pull the 'top' of the stack into the accumulator.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
PLA implied	1Ø4	$68	1	4

N	V	—	B	D	I	Z	C
*						*	

Operation The Stack Pointer is incremented by one, and the byte contained at this position in the stack is copied into the accumulator. If the byte is $ØØ the Zero flag is set. Bit 7 is copied into the Negative flag.

Applications Complements the operation of PHA to retrieve data previously pushed onto the stack.

References Pages: 59, 60

PLP

Pull the 'top' of the stack into the Status register.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
PLP implied	40	$28	1	4

N	V	—	B	D	I	Z	C
*	*		*	*	*	*	*

Operation The Stack Pointer is incremented by one and the byte contained at this position is copied into the Status register.

Applications Complements the operation of PHP to retrieve the previously pushed contents of the Status register, or to condition certain flags from a defined byte previously pushed onto the stack via the accumulator.

References Pages: 59, 60

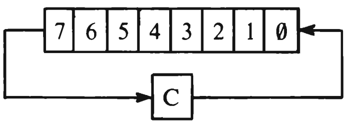
ROL

Rotate either the accumulator or a memory byte left by one bit with the Carry flag.

Addressing	Opcode Decimal	Opcode Hex	Bytes	Cycles
ROL accumulator	42	$2A	1	2
ROL zero page	38	$26	2	5
ROL zero page, X	54	$36	2	6
ROL absolute	46	$2E	3	6
ROL absolute, X	62	$3E	3	7

N	V	—	B	D	I	Z	C
*						*	*

Operation The specified byte and the contents of the Carry flag are rotated left by one bit in a circular manner.



Bit 7 is rotated into the Carry flag, with the flag's previous contents moving into bit 0. The remaining bits are shuffled left. The Negative flag is set if bit 6 previously held 1; cleared otherwise. The Carry flag is conditioned by bit 7, and if the specified byte now holds zero the Zero flag is set.

Applications Used in conjunction with ASL, ROL can be used to double the value of multibyte numbers, as the Carry bit is used to propagate the overflow from one byte to another. It may also be used before testing the Negative, Zero and Carry flags to determine the state of specific bits.

References Page: 80

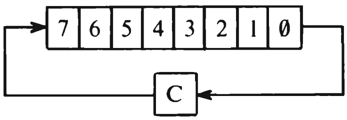
ROR

Rotate either the accumulator or a memory byte right by one bit with the Carry flag.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
ROR accumulator	106	$6A	1	2
ROR zero page	102	$66	2	5
ROR zero page, X	118	$76	2	6
ROR absolute	110	$6E	3	6
ROR absolute, X	126	$7E	3	7

N	V	—	B	D	I	Z	C
*						*	*

Operation The specified byte and the contents of the Carry flag are rotated right by one bit in a circular manner.



Bit 0 is rotated into the Carry flag with the flag's previous contents moving into the bit 7 position. The remaining bits are shuffled right. The Negative flag is set if the Carry flag was set previously; otherwise it is cleared. If bit 0 contained a 1 the Carry flag will now also be set. If the specified byte now holds zero the Zero flag is set.

Applications Used in conjunction with LSR, ROR can be used to halve the value of multibyte numbers. It may also be used before testing the Negative, Zero and Carry flags to determine the contents of specific bits.

References Pages: 80, 81

RTI

Return from interrupt.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
RTI implied	64	$40	1	6

N	V	—	B	D	I	Z	C
*	*		*	*	*	*	*

Operation This instruction expects to find three bytes on the stack. The first byte is pulled from the stack and placed into the Status register—thus conditioning all flags. The next two bytes are placed into the Program Counter. The Stack Pointer is incremented as each byte is pulled.

Applications Used to restore control to a program after an interrupt has occurred. On detecting the interrupt, the processor will have pushed the Program Counter and Status register onto the stack.

References Page: 130

RTS

Return from subroutine.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
RTS implied	96	$60	1	6

N	V	—	B	D	I	Z	C

Operation The two bytes on the top of the stack are pulled, incremented by one, and placed into the Program Counter. Program execution continues from this address. The Stack Pointer is incremented by two.

Applications Returns control from a subroutine to the calling program. It should therefore be the last instruction of a subroutine.

References Page: 72

SBC

Subtract specified byte from the accumulator with borrow.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
SBC #immediate	233	$E9	2	2
SBC zero page	229	$E5	2	3
SBC zero page, X	245	$F5	2	4
SBC absolute	237	$ED	3	4
SBC absolute, X	253	$FD	3	4/5
SBC absolute, Y	247	$F9	3	4/5
SBC (zero page, X)	225	$E1	2	6
SBC (zero page), Y	241	$F1	2	5/6

N	V	—	B	D	I	Z	C
*	*					*	*

Operation Subtracts the immediate value, or the byte contained at the specified address, from the contents of the accumulator. If the value is greater than the contents of the accumulator it will 'borrow' from the Carry flag, which should be set at the onset (only) of a subtraction. If the Carry flag is clear after the subtraction, a borrow has occurred. If the result is $ØØ the Zero flag is set. The contents of bit 7 are copied into the accumulator and V is set if an overflow from bit 6 to bit 7 occurred.

Applications Allows single, double and multibyte numbers to be subtracted from one another.

References Pages: 44, 46

SEC

Set the Carry flag (C = 1).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
SEC implied	56	$38	1	2

N	V	—	B	D	I	Z	C
							1

Operation A one is placed into the Carry flag bit position.

Applications Should always be used at the onset of subtraction as the Carry flag is taken into account by SBC.

References Pages: 32, 44

SED

Set the Decimal mode flag (D = 1).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
SED implied	248	$F8	1	2

N	V	—	B	D	I	Z	C
				1			

Operation A one is placed into the Decimal flag position.

Applications Puts the Commodore in decimal mode, in which Binary Coded Decimal (BCD) arithmetic is performed. The Carry flag now denotes a carry of hundreds, as the maximum value that can be encoded in a single BCD byte is 99.

References Page: 47

SEI

Set the Interrupt disable flag (I = 1).

Addressing	Opcode Decimal	Hex	Bytes	Cycles
SEI implied	12Ø	$78	1	2

N	V	—	B	D	I	Z	C
					1		

Operation A one is placed into the Interrupt flag position.

Applications When this flag is set *no* interrupts occurring on the IRQ line are processed. However NMI interrupts are processed, as are BREAKs.

References Page: 129

STA

Store the accumulator's contents in a memory location.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
STA zero page	133	$85	2	3
STA zero page, X	149	$95	2	4
STA absolute	141	$8D	3	4
STA absolute, X	157	$9D	3	5
STA absolute, Y	137	$99	3	5
STA (zero page, X)	129	$81	2	6
STA (zero page), Y	145	$91	2	6

N V — B D I Z C

Operations The contents of the accumulator are copied into the specified memory location.

Applications To save the contents of the accumulator, or to initialize areas of memory to specific values. Used in conjunction with LDA, blocks of data can be transferred from one area of memory to another.

References Page: 36

STX

Store the X register's contents in memory.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
STX zero page	134	$86	2	3
STX zero page, X	150	$96	2	4
STX absolute	142	$8E	3	4

N V — B D I Z C

Operation The contents of the X register are copied into the specified memory location.

Applications To save the X register's contents, or to initialize areas of memory to specific values.

References Page: 36

STY

Store the Y register's contents in memory.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
STY zero page	132	$84	2	3
STY zero page, X	148	$94	2	4
STY absolute	140	$8C	3	4

N	V	—	B	D	I	Z	C

Operations The contents of the Y register are copied into the specified memory location.

Applications To save the Y register's contents, or to initialize areas of memory to specific values.

References Page: 36

TAX

Transfer the accumulator's contents into the X register.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
TAX implied	170	$AA	1	2

N	V	—	B	D	I	Z	C
*						*	

Operation The contents of the accumulator are copied into the X register. If the X register now holds zero, the Zero flag is set. Bit 7 is copied into the Negative flag.

Applications Allows the accumulator's values to be saved temporarily, or perhaps used to seed the X register as a loop counter. Often used after PLA to restore the X register's contents previously pushed onto the stack.

References Page: 37

TAY

Transfer accumulator's contents into the Y register.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
TAY implied	168	$A8	1	2

N	V	—	B	D	I	Z	C
*						*	

Operation The contents of the accumulator are copied into the Y register. If the Y register now holds zero the Zero flag is set. Bit 7 is copied into the Negative flag.

Applications Allows the accumulator's values to be saved temporarily, or perhaps used to seed the Y register as a loop counter. Often used after PLA to restore the Y register's contents previously pushed onto the stack.

References Page: 37

TSX

Transfer the Stack Pointer's contents into the X register.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
TSX implied	186	$BA	1	2

N	V	—	B	D	I	Z	C
*						*	

Operation The contents of the Stack Pointer are copied into the X register. If X now holds zero, the Zero flag is set. Bit 7 is copied into the Negative flag.

Applications To calculate the amount of space left on the stack, or to save its current position while the stack contents are checked.

References Page: 61

TXA

Transfer the X Register's contents into the accumulator.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
TXA implied	138	$8A	1	2

N	V	—	B	D	I	Z	C
*						*	

Operation The contents of the X register are copied into the accumulator. If the accumulator now holds zero the Zero flag is set. Bit 7 is copied into the Negative flag.

Applications Allows the X register's contents to be manipulated by logical or arithmetic instructions. Followed by a PHA it allows the X register's value to be saved on the stack.

References Page: 37

TXS

Transfer the X Register's contents into the Stack Pointer.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
TXS implied	154	$9A	1	2

N	V	—	B	D	I	Z	C

Operation The contents of the X register are copied into the Stack Pointer.

Applications Allows the contents of the Stack Pointer to be set or reset to a specific value. For example, on 'power-up' or BREAK, the OS executes:

```
LDX #$FF
TXS
```

to 'clear' the stack and reset the Stack Pointer.

References Page: 61

TYA

Transfer the Y register's contents into the accumulator.

Addressing	Opcode Decimal	Hex	Bytes	Cycles
TYA implied	152	$98	1	2

N	V	—	B	D	I	Z	C
*						*	

Operation The contents of the Y register are copied into the accumulator. If the accumulator now holds zero the Zero flag is set. Bit 7 is copied into the Negative flag.

Applications Allows the Y register's contents to be manipulated by logical or arithmetic instructions. When followed by a PHA, it allows the Y register's value to be saved on the stack.

References Page: 37

4 Instruction Cycle Times

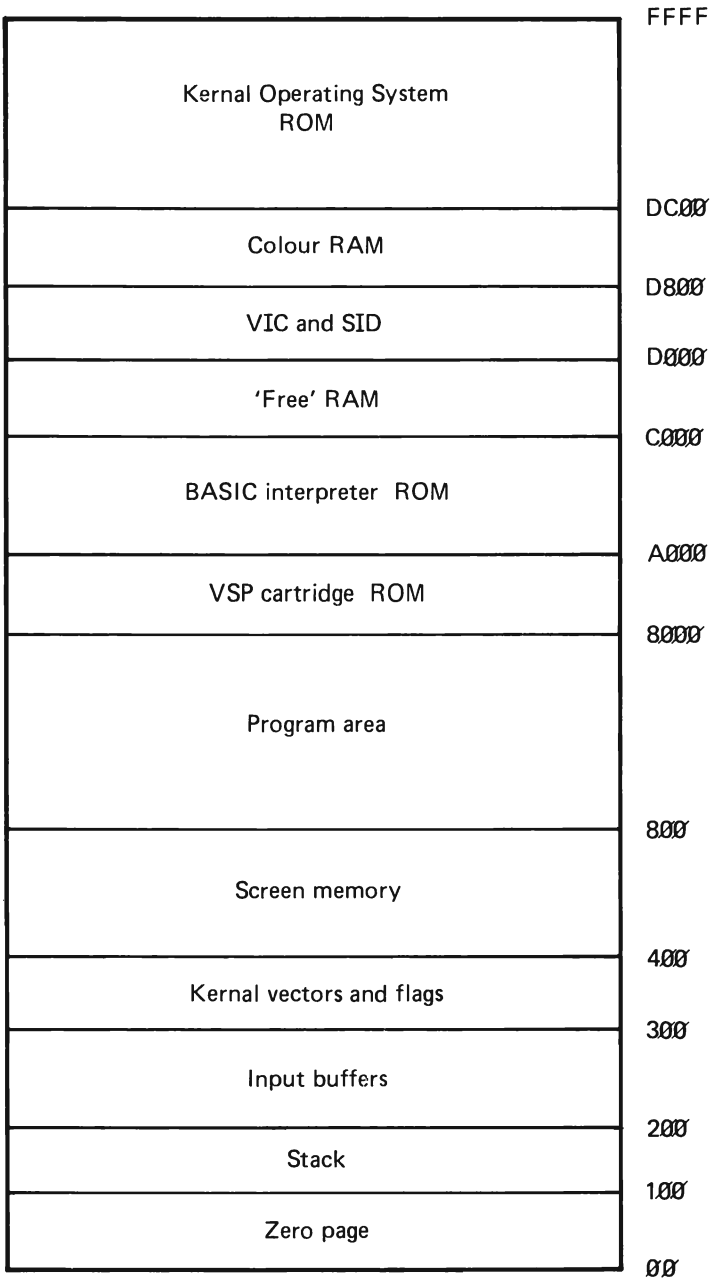
	Implied	Relative	Immediate	Zero page	Zero page, X	Absolute	Absolute, X	Absolute, Y	(Zero page, X)	(Zero page), Y	(Indirect)
ADC	—	—	2	3	4	4	4*	4*	6	5*	—
AND	—	—	2	3	4	4	4*	4*	6	5*	—
ASL	2	—	—	5	6	6	7	—	—	—	—
BCC	—	2**	—	—	—	—	—	—	—	—	—
BCS	—	2**	—	—	—	—	—	—	—	—	—
BEQ	—	2**	—	—	—	—	—	—	—	—	—
BIT	—	—	—	3	—	4	—	—	—	—	—
BMI	—	2**	—	—	—	—	—	—	—	—	—
BNE	—	2**	—	—	—	—	—	—	—	—	—
BPL	—	2**	—	—	—	—	—	—	—	—	—
BRK	7	—	—	—	—	—	—	—	—	—	—
BVC	—	2**	—	—	—	—	—	—	—	—	—
BVS	—	2**	—	—	—	—	—	—	—	—	—
CLC	2	—	—	—	—	—	—	—	—	—	—
CLD	2	—	—	—	—	—	—	—	—	—	—
CLI	2	—	—	—	—	—	—	—	—	—	—
CLV	2	—	—	—	—	—	—	—	—	—	—
CMP	—	—	2	3	4	4	4*	4*	6	5*	—

	Implied	Relative	Immediate	Zero page	Zero page, X	Absolute	Absolute, X	Absolute, Y	(Zero page, X)	(Zero page, Y)	(Indirect)
CPX	—	—	2	3	—	4	—	—	—	—	—
CPY	—	—	2	3	—	4	—	—	—	—	—
DEC	—	—	—	5	6	6	7	—	—	—	—
DEX	2	—	—	—	—	—	—	—	—	—	—
DEY	2	—	—	—	—	—	—	—	—	—	—
EOR	—	—	2	3	4	4	4*	4*	6	5*	—
INC	—	—	—	5	6	6	7	—	—	—	—
INX	2	—	—	—	—	—	—	—	—	—	—
INY	2	—	—	—	—	—	—	—	—	—	—
JMP	—	—	—	—	—	3	—	—	—	—	5
JSR	—	—	—	—	—	6	—	—	—	—	—
LDA	—	—	2	3	4	4	4*	4*	6	5*	—
LDX	—	—	2	3	4	4	—	4*	—	—	—
LDY	—	—	2	3	4	4	4*	—	—	—	—
LSR	2	—	—	5	6	6	7	—	—	—	—
NOP	2	—	—	—	—	—	—	—	—	—	—
ORA	—	—	2	3	4	4	4*	4*	6	5*	—
PHA	3	—	—	—	—	—	—	—	—	—	—
PHP	3	—	—	—	—	—	—	—	—	—	—
PLA	4	—	—	—	—	—	—	—	—	—	—
PLP	4	—	—	—	—	—	—	—	—	—	—
ROL	2	—	—	5	6	6	7	—	—	—	—
ROR	2	—	—	5	6	6	7	—	—	—	—
RTI	6	—	—	—	—	—	—	—	—	—	—
RTS	6	—	—	—	—	—	—	—	—	—	—
SBC	—	—	2	3	4	4	4*	4*	6	5*	—
SEC	2	—	—	—	—	—	—	—	—	—	—
SED	2	—	—	—	—	—	—	—	—	—	—
SEI	2	—	—	—	—	—	—	—	—	—	—

	Implied	Relative	Immediate	Zero page	Zero page, X	Absolute	Absolute, X	Absolute, Y	(Zero page, X)	(Zero page), Y	(Indirect)
STA	—	—	—	3	4	4	5	5	6	6	—
STX	—	—	—	3	4	4	—	—	—	—	—
STY	—	—	—	3	4	4	—	—	—	—	—
TAX	2	—	—	—	—	—	—	—	—	—	—
TAY	2	—	—	—	—	—	—	—	—	—	—
TSX	2	—	—	—	—	—	—	—	—	—	—
TXA	2	—	—	—	—	—	—	—	—	—	—
TXS	2	—	—	—	—	—	—	—	—	—	—
TYA	2	—	—	—	—	—	—	—	—	—	—

*Add 1 cycle if page boundary crossed.
**Add 1 if branch occurs to same page or add 2 if branch occurs to a different page.

5 Commodore 64 Memory Map



6 Branch Calculators

The branch calculators are used to give branch values in hex. First, count the number of bytes you need to branch. Then locate this number in the centre of the appropriate table, and finally, read off the high and low hex nibbles from the side column and top row respectively.

Example For a backward branch of 16 bytes:

Locate 16 in the centre of Table A6.1 (bottom row), then read off high nibble (#F) and low nibble (#Ø) to give displacement value (#FØ).

Table A6.1 Backward branch calculator

LSD / MSD	Ø	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
8	128	127	126	125	124	123	122	121	12Ø	119	118.	117	116	115	114	113
9	112	111	11Ø	1Ø9	1Ø8	1Ø7	1Ø6	1Ø5	1Ø4	1Ø3	1Ø2	1Ø1	1ØØ	99	98	97
A	96	95	94	93	92	91	9Ø	89	88	87	86	85	84	83	82	81
B	8Ø	79	78	77	76	75	74	73	72	71	7Ø	69	68	67	66	65
C	64	63	62	61	6Ø	59	58	57	56	55	54	53	52	51	5Ø	49
D	48	47	46	45	44	43	42	41	4Ø	39	38	37	36	35	34	33
E	32	31	3Ø	29	28	27	26	25	24	23	22	21	2Ø	19	18	17
F	16	15	14	13	12	11	1Ø	9	8	7	6	5	4	3	2	1

Table A6.2 Forward branch calculator

LSD / MSD	Ø	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
Ø	Ø	1	2	3	4	5	6	7	8	9	1Ø	11	12	13	14	15
1	16	17	18	19	2Ø	21	22	23	24	25	26	27	28	29	3Ø	31
2	32	33	34	35	36	37	38	39	4Ø	41	42	43	44	45	46	47
3	48	49	5Ø	51	52	53	54	55	56	57	58	59	6Ø	61	62	63
4	64	65	66	67	68	69	7Ø	71	72	73	74	75	76	77	78	79
5	8Ø	81	82	83	84	85	86	87	88	89	9Ø	91	92	93	94	95
6	96	97	98	99	1ØØ	1Ø1	1Ø2	1Ø3	1Ø4	1Ø5	1Ø6	1Ø7	1Ø8	1Ø9	11Ø	111
7	112	113	114	115	116	117	118	119	12Ø	121	122	123	124	125	126	127

7 6510 Opcodes

All numbers are hexadecimal.

00 BRK implied
01 ORA (zero page, X)
02 Future expansion
03 Future expansion
04 Future expansion
05 ORA zero page
06 ASL zero page
07 Future expansion
08 PHP implied
09 ORA #immediate
0A ASL accumulator
0B Future expansion
0C Future expansion
0D ORA absolute
0E ASL absolute
0F Future expansion
10 BPL relative
11 ORA (zero page), Y
12 Future expansion
13 Future expansion
14 Future expansion
15 ORA zero page, X
16 ASL zero page, X
17 Future expansion
18 CLC implied
19 ORA absolute, Y
1A Future expansion
1B Future expansion
1C Future expansion
1D ORA absolute, X
1E ASL absolute, X
1F Future expansion
20 JSR absolute
21 AND (zero page, X)
22 Future expansion
23 Future expansion
24 BIT zero page
25 AND zero page
26 ROL zero page
27 Future expansion
28 PLP implied
29 AND #immediate
2A ROL accumulator
2B Future expansion
2C BIT absolute
2D AND absolute
2E ROL absolute
2F Future expansion
30 BMI relative
31 AND (zero page), Y
32 Future expansion
33 Future expansion
34 Future expansion
35 AND zero page, X
36 ROL zero page, X
37 Future expansion

38 SEC implied
39 AND absolute, Y
3A Future expansion
3B Future expansion
3C Future expansion
3D AND absolute, X
3E ROL absolute, X
3F Future expansion
40 RTI implied
41 EOR (zero page, X)
42 Future expansion
43 Future expansion
44 Future expansion
45 EOR zero page
46 LSR zero page
47 Future expansion
48 PHA implied
49 EOR #immediate
4A LSR accumulator
4B Future expansion
4C JMP absolute
4D EOR absolute
4E LSR absolute
4F Future expansion
50 BVC relative
51 EOR (zero page), Y
52 Future expansion
53 Future expansion
54 Future expansion
55 EOR zero page, X
56 LSR zero page, X
57 Future expansion
58 CLI implied
59 EOR absolute, Y
5A Future expansion
5B Future expansion
5C Future expansion
5D EOR absolute, X
5E LSR absolute, X
5F Future expansion
60 RTS implied
61 ADC (zero page, X)
62 Future expansion
63 Future expansion
64 Future expansion
65 ADC zero page
66 ROR zero page
67 Future expansion
68 PLA implied
69 ADC #immediate
6A ROR accumulator
6B Future expansion
6C JMP (indirect)
6D ADC absolute
6E ROR absolute
6F Future expansion
70 BVS relative
71 ADC (zero page), Y
72 Future expansion
73 Future expansion
74 Future expansion
75 ADC zero page, X
76 ROR zero page, X
77 Future expansion
78 SEI implied
79 ADC absolute, Y
7A Future expansion
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81 STA (zero page, X)
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87 Future expansion

88 DEY implied
89 Future expansion
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D8 CLD implied
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Program Index

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