CS 155 Computer Organization

Notes – Chapter 1
Binary Numbers and Codes

- **Number Systems**

  A number system contains the number of digits named as its base.
  If the base is n, then the digits are $0, \ldots, n-1$.
  For example,

Base #	Name	Digits
Base 10	*Decimal*	0,1,2,3,4,5,6,7,8,9
Base 2	*Binary*	0,1
Base 8	*Octal*	0,1,2,3,4,5,6,7
Base 16	*Hexadecimal*	0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F

Note : "New" digits (A,B,C,D,E,F) must be "invented" for use in a **hexadecimal** system. Other symbols could be used, but these appeal logically and are the convention used throughout this course.

Problems :
Given a number and its base, write the next 5 numbers in that base.

$(97)_{10}$ ________, ________, ________, ________, ________

$(775)_8$ ________, ________, ________, ________, ________

$(1011)_2$ ________, ________, ________, ________, ________

$(9FD)_{16}$ ________, ________, ________, ________, ________

Note that the largest digit in another base acts just like a 9 in Base 10.

- **Converting from another Base to the Decimal**

Follow these steps when converting from any other base to decimal *base 10* **.**

1. Write the column value for each number above each digit.
2. Multiply each digit by its column value *(multiply using base 10)*.
3. Sum them up.

Example — Base 5 to Decimal *(Base 10)*

$342_5 = (?)_{10}$

$$\begin{array}{lllr} 342_5 = & 2 \times 5^0 \Rightarrow & 2 \times 1 = & 2 \\ & 4 \times 5^1 \Rightarrow & 4 \times 5 = & 20 \\ & 3 \times 5^2 \Rightarrow & 3 \times 25 = & 75 \\ \hline & & & 97_{10} \end{array}$$

Exercise — Base 8 *(octal)* **to Decimal** *(Base 10)*

$7241_8 = (?)_{10}$

Exercise — Base 16 *(hexadecimal)* **to Decimal** *(Base 10)*

$4E3_{16} = (?)_{10}$

Exercise — Base 2 *(binary)* **to Decimal** *(Base 10)*

$01101001_2 = (?)_{10}$

- **Converting from Decimal to Another Base**

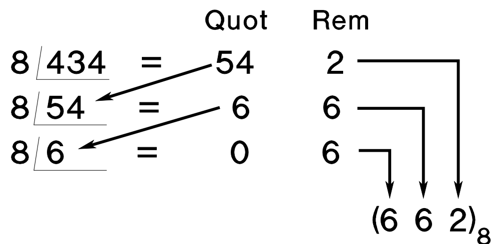
There are 2 methods for converting from decimal to other bases

1. **<u>The Division Method</u>, and**
2. **<u>The Subtraction Method</u>.**

Example — using the Division Method

METHOD: Divide by the base. The remainer becomes the least significant digit. Then take the quotient and repeat, until the quotient becomes zero.

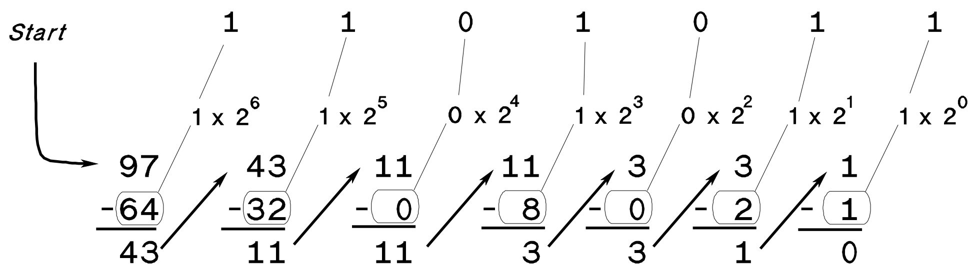
$434_{10} = (?)_8$ $\quad$ $289_{10} = (?)_16$



Example — using the Subtraction Method. Most useful for relatively small numbers. The method to use when computing "in your head."

METHOD: Find the largest b^n (b = base) that is *smaller* than the number. Find the largest *multiple* of that value that is smaller than the number. Subtract this value from the number. Repeat the process with the powers $n-1$, $n-2$, ..., 0.

$97_{10} = (?)_2$



$41_{10} = (?)_8$

- **Converting from a non-decimal Base to a non-decimal Base**

The key to this type of conversion is to use Base 10 *(Decimal)* as the "bridge".

$$Number_{given\ base} \rightarrow Equivalent_{Base\ 10} \rightarrow Equivalent_{desired\ base}$$

That is, you should convert your given number to base 10, then use that result to convert to the desired base.

Example — Convert $(1AF)_{16}$ to Base 5.

Step 1: Convert $1AF_{16}$ to Decimal

$F \times 16^0 \Rightarrow 15 \times 1 = 15$

$A \times 16^1 \Rightarrow 10 \times 16 = 160$

$1 \times 16^2 \Rightarrow 1 \times 256 = 256$

$(431)_{10}$

Step 2: Convert 431_{10} to Base 5

		Quot	Rem
5 / 431	=	86	1
5 / 86	=	17	1
5 / 17	=	3	2
5 / 3	=	0	3

$(3\ 2\ 1\ 1)_5$

Exercise — Convert $(1632)_7$ to Base 12.

• Simplified Conversions between Binary, Octal and Hexadecimal

Because Binary (Base 2), Octal (Base 8) and Hexadecimal (Base 16) are all powers of 2 (2 = 2^1, 8 = 2^3, 16 = 2^4), there is a process to easily convert between them.

Conversion to Octal from Binary

Group binary digits by 3 from the decimal point outward (both left and right). View each group of 3 digits of binary numbers and convert to octal for each group; Pad with zeros for groups less than 3.

Example - 11001100.11 binary to octal

$$\underbrace{011}_{3}\ \underbrace{001}_{1}\ \underbrace{100}_{4}\ .\ \underbrace{110}_{6}$$

Conversion to Hexadecimal from Binary

Group binary digits by 4 from the decimal point outward (both left and right). View each group of 4 digits of binary numbers and convert to hexadecimal for each group; Pad with zeros for groups less than 4.

Exercise - 0111 0101 1100.101 binary to hexadecimal

Conversion between Hexadecimal and Octal

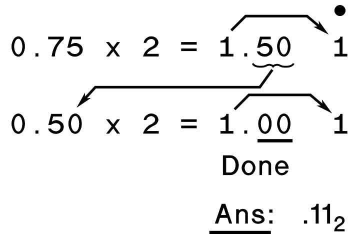
Rule : When converting between Hexadecimal and Octal *(either Hexadecimal → Octal OR Octal → Hexadecimal)* **first convert to Binary, then convert to the target base.**
In other words use Binary as the "bridge" between these 2 bases.

Exercise - $(7512)_8$ to $(?)_{16}$

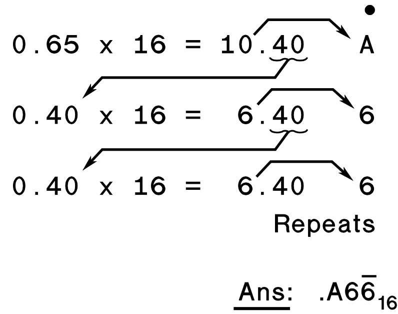
- **Converting Fractional Portions of Decimal** *(Base 10)* **Numbers to Other Bases**

Process: Multiply the decimal portion by the "new" base number. The integer is retained for the new number. Continue the process until zero is reached or the desired number of digits is attained.

Example - Convert $(0.75)_{10}$ **to Binary**



Convert $(0.65)_{10}$ **to Hexadecimal**



Exercise - Convert $(0.312)_{10}$ to $(?)_8$

- **A little "bit" and a lot** *(of bits)*

A **bit** is a binary digit. *(0, 1)*

Large quantities of bits (and bytes) have names you should become familiar with. Here are a few names along with values.

Greek Prefix	Abbrevi-ation	Exponential Form	Actual Value	Approximate Value
Kilo	**K**	2^{10}	1,024	1,000
Mega	**M**	2^{20}	1,048,576	1,000,000
Giga	**G**	2^{30}	1,073,741,824	1,000,000,000

An interesting fact - Disk drive manufacturers use the "rounded" (approximate) values when specifying disk capacities, because they sound more impressive! That is why that new 1 Gigabyte drive actually ends up containing only 931.3 mB!

- **Adding in Other Bases**

Example

Octal:

```
       1   (carry)
   7 1 3 5
 + 5 6 2 3
 ---------
  14 7 6 0
```

$12_{10} = 14_8$ $8_{10} = 10_8$!

Exercise

Hex

```
  A 4 F 1
+ 3 8 1 A
---------
```

- **Subtracting in Other Bases**

The method shown here is not the method used by a computer. It is shown here so that you will have a "new method" to use to check your answers. The method you will be accountable for is the one explained in the next section.

Example

Octal:

```
   borrow
   6 11 = 9₁₀
   7 1 3 5
 - 5 6 2 3
 ---------
   1 3 1 2
```

Exercise

Hex

```
  D A 1 7
- 7 4 3 A
---------
```

- **Signed Binary Numbers**

How can we represent a **negative integer**? Since a computer stores only 0's and 1's, it cannot place a "–" sign on a number. Somehow the concept of negative must be expressed using only 0's and 1's. There are several ways to represent negative numbers; we will consider three:

1. **Signed Magnitude**,
2. **Signed-1's Complement**, and
3. **Signed-2's Complement**,

In each of these representations, the left-most bit is called the **Sign Bit**. A `'0'` in the Sign Bit indicates that the number is **Positive**. A `'1'` in the Sign Bit indicates that the number is **Negative**. When you look at the machine's "raw " representation of the number (which sometimes must be done when using assembly or machine language), it is important to be able to correctly interpret the value of the number.

In all three systems, the representations for *positive* numbers are the same. However, the three systems vary in the way they represent negative numbers.

NOTE: The following sections discuss only how to *use* the complement systems. For a more complete (mathematical) treatment of how they work, see the Appendix on Complement Arithmetic.

- **Signed Magnitude :**

We are already familiar with signed magnitude, since this is the system that our "regular" arithmetic system uses (except, of course, here we represent the values in base 2 rather than base 10). A positive number is represented by taking the unsigned binary representation of the number, and adding a leading zero (the sign bit). A negative number is represented by taking the unsigned binary (absolute value) representation of the number, and adding a leading one.

Example. Find the signed magnitude representations for $+27_{10}$ and -47_{10}, using 8 bits.

Ans:
+27 is positive, so the signed magnitude representation is:

$$+27_{10} = 16 + 8 + 2 + 1 = \boxed{0}001\ 1011$$

−47 is negative, so take the positive representation for 45, then add a 1 sign bit:

$$-(47_{10}) = -(32 + 8 + 4 + 2 + 1) = \boxed{1}010\ 1111$$

Example. Take the negative of 1101 0010.

Ans:

$$-(11010010) = \boxed{0}010\ 1101$$

The addition of 2 numbers in signed magnitude form follows the same rules of ordinary arithmetic. While this system is very natural for us to use, since we have practiced it since early grade school, the rules for performing arithmetic are fairly complicated, and require some decisions to be made in the process. The rules for addition are:

- If both numbers are *positive*, then add the two numbers, and append a sign bit of zero (for positive) to the answer.
- If both numbers are *negative*, then add the absolute values of the two numbers, and append a 1 (for negative) to the answer.
- If the numbers are *opposite* in sign, subtract the smaller absolute value number from the larger absolute value number, and then append the sign of the larger absolute value number to the answer.

For subtraction, change the sign of the second number (i.e., "take the negative" of the second number), and then follow the same rules as for addition.

This method is complicated for a computer, because it requires the comparison of the two numbers first before deciding what rule to follow, AND it involves the use of two different procedures - ADD and SUBTRACT. Surprisingly, the next two number systems avoid these problems!

- **One's Complement:**

In the *1's Complement system*, positive numbers are represented **the same as before**, i.e., just like unsigned (and signed magnitude), with a leading zero (to represent a positive sign). However, negative numbers are formed by taking the positive (absolute value) of the number, and **switching all the 1's to 0's, and all the 0's to 1's**. This process, which is called **"taking the 1's complement"** of a number, is equivalent to **"taking the negative"** of the number. The sign bit is treated no differently than any of the other bits.

Example. Find the 1's complement representations for $+27_{10}$ and -47_{10}, using 8 bits.

Ans:

+27 is positive, so the 1's complement representation is the same as the unsigned value:

$$+27_{10} = 16 + 8 + 2 + 1 = 0001\ 1011$$

−47 is negative, so start with the positive representation for 47, then take the 1's complement ("take the negative"):

$$-(47_{10}) = -(32 + 8 + 4 + 2 + 1) = -(0010\ 1111) = 1101\ 0000$$

Example. Take the 1's complement (i.e., take the negative) of 1101 0010.

Ans: Switch all the bits:

$$-(1101\ 0010) = 0010\ 1101$$

Exercise. Find the 1's complement representation for $+87_{10}$ using 8 bits.

Exercise. Find the 1's complement representation for -39_{10} using 8 bits.

Exercise. Find the 1's complement representation for -57_{10} using 8 bits.

The rules for addition and subtraction in 1's complement are simpler than for signed magnitude, at least for the computer, since no decisions need be made before performing the operations. **The rules are the same, regardless of whether the numbers are positive or negative!** The rules for addition are:

- Add the two numbers (including the sign bits).
- If the carry out of the sign bit is a 1, add it to the answer. (End-Around Carry).

To subtract, take the complement of (i.e., "take the negative of") the second number, then add (using the rules above).

Example. Perform the following *1's complement* arithmetic. Also show each problem in base 10.

```
  0001 1011        1110 1011        0100 1101        1101 0110
 +0010 1110       +0011 0101       -0101 0100       -0001 1011
```

Ans: For the addition problems, we simply add:

```
  0001 1011  = +27                  1110 1011  = -(0001 0100) = -20
 +0010 1110  = +46                 +0011 0101  =                +53
  0100 1001  = +73                  0010 0000
                                           +1  End around carry
                                    0010 0001                   = +33
```

For subtraction, we take the complement (of the second number) and add:

```
  0100 1101 =    +77  ⇒   0100 1101  =                  +77
 -0101 0100 = -(+84)  ⇒  +1010 1011  =                  -84
                          1111 1000  = -(0000 0111) =    -7
```

```
 1101 0110                            ⇒  1101 0110 = -(0010 1001) = -41
-0001 1011 = -(0001 1011) = -(+27)  ⇒ +1110 0100 =                  -27
                                         1011 1010
                                                +1 End around carry
                                         1011 1011 = -(0100 0100) = -68
```

The advantage of the 1's complement system is that the arithmetic operations are the same, regardless of the signs of the numbers. Thus, no comparisons or decisions need be made before performing the operations. Also, note that only one operation, addition, is ever needed to compute the answer.

A problem with 1's complement arithmetic involves the value zero:

Example. Find the 1's complement of 0000 0000.

Ans:

-(0000 0000) = 1111 1111

There are representations for both positive and negative zero! This makes it awkward to compare numbers with zero, since two comparisons must be performed. The 2's complement system solves this problem.

Exercise. Perform the following *1's complement* arithmetic. Also show each problem in base 10.

```
 0000 1011      1101 0001      1111 0001      1110 1011
+0110 0110     +0010 1101     -1101 0100     -0011 0111
```

Ans:

- **Two's Complement:**

In *2's complement*, positive numbers are represented the same as unsigned numbers with a leading zero. Negative numbers are formed by taking the 1's complement ("switching all the bits") **and adding one**. This process is called "taking the 2's complement," and is equivalent to "taking the negative" of a number.

Example. Find the 2's complement representations for $+27_{10}$ and -47_{10}, using 8 bits.
Ans:
$+27$ is positive, so the 2's complement representation is simply:

$$+27_{10} = 16 + 8 + 2 + 1 = 00011011$$

-47 is negative, so take the positive representation for 47, then take the 2's complement ("take the negative"):

$$-(47_{10}) = -(32 + 8 + 4 + 2 + 1) = -(00101111) = 11010000 + 1 = 11010001$$

Example. Take the 2's complement (i.e., take the negative) of 11010010.
Ans: Switch all the bits and add one:

$$-(11010010) = 00101101 + 1 = 00101110$$

Example. Take the 2's complement (i.e., take the negative) of 00000000.
Ans: Remember that we throw away any carries out of the sign bit!

$$-(00000000) = 11111111 + 1 = 00000000$$

NOTE: There is a single representation for zero!

Exercise. Find the 2's complement representation for $+37_{10}$ using 8 bits.

Exercise. Find the 2's complement representation for -41_{10} using 8 bits.

Exercise. Find the 2's complement representation for -108_{10} using 8 bits.

The rules for addition and subtraction in 2's complement are even simpler than for 1's complement, since there is no end around carry. For addition, add the two numbers (**Ignore** any carries out of the sign bit). To subtract, take the 2's complement of (i.e., "take the negative of") the second number, then add.

Example. Perform the following *2's complement* arithmetic. Also show each problem in base 10.

```
 0001 1011      1110 1011      0100 1101      1101 0110
+0010 1110     +0011 0101     -0101 0100     -0001 1011
```

Ans: For the addition problems, simply add (ignoring carries out):

```
 0001 1011  = +27             1110 1011  = -(0001 0101) = -21
+0010 1110  = +46            +0011 0101  =                +53
 0100 1001  = +73             0010 0000                 = +32
```

For subtraction, take the complement and add:

```
 0100 1101 =    +77  ⇒   0100 1101  =                   +77
-0101 0100 = -(+84)  ⇒  +1010 1100  =                   -84
                         1111 1001  = -(0000 0111) =    -7

 1101 0110                          ⇒  1101 0110 = -(0010 1010) = -42
-0001 1011 = -(0001 1011) = -(+27)  ⇒ +1110 0101 =                -27
                                       1011 1011 = -(0100 0101) = -69
```

The 2's complement system trades off a slightly more difficult "complementing" process (you must complement **and** add one) for a slightly simpler addition process (no end around carry) and, even more importantly, a consistent representation for zero, when compared with 1's complement. For the latter reason, 2's complement is the representation used for integers in virtually ALL computers today.

Also Note: *2's complement* binary numbers and *unsigned* binary numbers are added using the same rules – only the interpretation of the numbers is different! Therefore, computers need only one common hardware circuit to handle both types of arithmetic!

Exercise. Perform the following *2's complement* arithmetic. Also show each problem in base 10.

```
 0010 1010      1110 1101      1010 1001      1110 1011
+0011 0110     +0110 1101     -1101 0100     -0001 0010
```

Ans:

Example. Find the 8 bit and 16 bit *2's complement* representations for +5 and -5.

Ans:

For +5, the representations are the same as for the 8 and 16 bit unsigned values:

$$+5 = (4+1) = 00000101_{8bit} = 0000000000000101_{16bit}$$

For -5, switch all the bits and add 1 for each representation:

$$-5 = 11111011_{8bit} = 1111111111111011_{16bit}$$

Note: To express a *2's complement* value in a larger number of bits, the value is **sign-extended** – that is, the sign bit is replicated to make up the required number of bits.

• Overflow

Overflow occurs whenever a value is too large to be represented in the specified number of bits. In signed representations, this occurs when there are not enough bits to include a sign bit:

Example. Express the value $+142_{10}$ as an eight bit 2's complement number.

Ans:

$$+142_{10} = (128+8+4+2+1) = 1000\ 1111$$

But no room for a sign in 8 bits!

While this value could be represented as an unsigned value in 8 bits (i.e., no sign bit), there are not enough bits available to represent this value in 2's complement (or any other signed representation). For unsigned numbers of n bits, the values that can be represented range from $0 \rightarrow (2^n - 1)$. For the signed representations, since one bit must be used for the sign, the range is $-(2^{n-1}-1) \rightarrow +(2^{n-1}-1)$. (The low end for 2's complement is actually -2^{n-1}.)

Overflow also manifests itself when doing complement arithmetic. There are two ways to detect overflow when doing *1's* and *2's complement* arithmetic (they are both mathematically equivalent):

1. If the addition of two positive numbers yields a negative result, or vice versa.
2. If there is a carry out of the sign bit, but no carry in, or versa. (No carries, or a carry in AND a carry out are OK!)

The first case is most likely what we would observe during overflow, while the second case is the way a computer detects overflow.

Example. Perform the following *2's complement* arithmetic. Also show each problem in base 10.

Ans:

```
  0101 1011  =  +91          1011 1101  ⇒  1011 1101 =   -67
 +0110 1110  = +110         -0101 0100  ⇒ +1010 0100 = -(+84)
  1100 1001  =  -55 ???      0010 0000     0110 0001     +97 ???
 (Carry in, no carry out)       (Carry out, no carry in)
```

- **Comparing the Three Signed Representations**

In all three signed representations, a positive number is expressed in the same way – the same as the unsigned value, with at least one zero appended on the front. For example, the value 9_{10} would be expressed as 0000 1001 in eight bits on all three systems. However, the representations for negative values are different in each system; the only common characteristic is that the left-most (sign) bit is a one. For example, -9_{10} in each system would look like:

Signed-mag: `1000 1001` *1's comp:* `1111 0110` *2's comp:* `1111 0111`

Reconstruct TABLE 1-3 (p. 15) in the space provided. Understand why each integer is represented the way it is.

Decimal	2's Complement	1's Complement	Signed Magnitude
+7	**0111**	**0111**	**0111**
+6			
+5			
+4			
+3			
+2			
+1			
+0			
−0			
−1			
−2			
−3			
−4			
−5			
−6			
−7			
−8			

For each of the binary patterns below, show the represented value in decimal for each of the signed representations:

Binary value	Signed-mag	1's Complement	2's Complement
$(10\ 0010)_2$			
$(0111\ 0111)_2$			
$(1110\ 0010)_2$			
$(1001\ 1011)_2$			

- **Summary of Rules for Complement Arithmetic**

For 1's Complement:

Positive numbers: Represented the **SAME AS** an unsigned value (with at least one leading zero).

Negative numbers: Computed from the positive value by "switching all the bits"

Addition:
1. Simply ADD THE NUMBERS. It makes no difference that either or both of the numbers is negative!
2. If there was a carry out of the sign bit, add 1 to the result (end-around carry).

Subtraction: Take the 1's complement of the second number, then add (as above).

For 2's Complement:

Positive numbers: Represented the **SAME AS** an unsigned value (with at least one leading zero).

Negative numbers: Computed from the positive value by "switching all the bits" and adding one.

Addition: Simply ADD THE NUMBERS. It makes no difference that either or both of the numbers is negative!

Subtraction: Take the 2's complement of the second number, then add.

- **Floating Point Numbers**

We will not be using Floating Point (`real` or `float`) Numbers in this class. However, for completeness, their representation is included here. Floating Point numbers are stored as a *mantissa* (fraction) and *exponent* - the exact number of bits used for each part determines the maximum and minimum values, and the accuracy (number of digits) that can be stored. While virtually all computers use 2's complement for storing `ints`, each computer uses its own unique floating point format. An attempt to standardize the way that computers store floating point values resulted in the **IEEE Format**, whose bit layout and resulting maximum and minimum values are shown on the next page. Many of the more recent computer designs now use this format, and some of the older machines have been "retrofitted" with this format, making it easier to transfer data between different machines.

S	*Exponent*	*Mantissa (fraction)*

S – **Sign Bit (0 for positive, 1 for negative)**

exp – **exponent, base 2, 8 bits for single, 11 bits for double**

mantissa – **fraction, base 2, radix pt assumed to be in front of number, 23 bits for single, 52 bits for double**

Range – **single, $\pm 2^{\pm 127}$, ($\approx \pm 10^{\pm 38}$), double, $\pm 2^{\pm 1023}$, ($\approx \pm 10^{\pm 308}$)**

Accuracy – **single, 24 bits (more than 7 decimal digits)**
– **double, 53 bits (almost 16 decimal digits)**

- **Decimal Codes**

There are a number of decimal codes in use. You are already familiar with the binary, octal, decimal and hexadecimal systems. The binary system is the most natural system for a computer. Humans are used to a decimal system. For this reason, the Binary Coded Decimal (BCD) system was invented. Some computers store BCD numbers. Each digit in a BCD number is represented by 4 bits. Copy TABLE 1-4 (p. 18) in the space below.

It is important to realize that BCD numbers are actually *decimal* numbers and *not* binary numbers, even though they are represented in bits. There are other decimal codes, but this is the only one that will be highlighted here.

- **Alphanumeric (character) Codes**

There are a number of different codes for representing characters. Two of the most prominent are listed below :

  – ASCII – *American Standard Code for Information Interchange*
  – EBCDIC – *Extended Binary Coded Decimal Interchange Code*

ASCII Character Set

LSD \ MSD	0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7
0	000 NUL 0 Null Char	020 DLE 16 Data Link Escape	040 SP 32 Space	060 0 48	0100 @ 64	0120 P 80	0140 ` 96	0160 p 112
1	001 SOH 1 Start of Header	021 DC1 17 Device Control 1	041 ! 33	061 1 49	0101 A 65	0121 Q 81	0141 a 97	0161 q 113
2	002 STX 2 Start of Transmission	022 DC2 18 Device Control 2	042 " 34	062 2 50	0102 B 66	0122 R 82	0142 b 98	0162 r 114
3	003 ETX 3 End of Transmission	023 DC3 19 Device Control 3	043 # 35	063 3 51	0103 C 67	0123 S 83	0143 c 99	0163 s 115
4	004 EOT 4 End of Tape	024 DC4 20 Device Control 4	044 $ 36	064 4 52	0104 D 68	0124 T 84	0144 d 100	0164 t 116
5	005 ENQ 5 Enquire	025 NAK 21 Negative Acknowledge	045 % 37	065 5 53	0105 E 69	0125 U 85	0145 e 101	0165 u 117
6	006 ACK 6 Acknowledge	026 SYN 22 Synchronize	046 & 38	066 6 54	0106 F 70	0126 V 86	0146 f 102	0166 v 118
7	007 BEL 7 Bell	027 ETB 23 End Transmission Block	047 ' 39	067 7 55	0107 G 71	0127 W 87	0147 g 103	0167 w 119
8	010 BS 8 Backspace	030 CAN 24 Cancel	050 (40	070 8 56	0110 H 72	0130 X 88	0150 h 104	0170 x 120
9	011 HT 9 Horizontal Tab	031 EM 25 End of Medium	051) 41	071 9 57	0111 I 73	0131 Y 89	0151 i 105	0171 y 121
A	012 LF 10 Line Feed	032 SUB 26 Substitute	052 * 42	072 : 58	0112 J 74	0132 Z 90	0152 j 106	0172 z 122
B	013 VT 11 Vertical Tab	033 ESC 27 Escape	053 + 43	073 ; 59	0113 K 75	0133 [91	0153 k 107	0173 { 123
C	014 FF 12 Form Feed	034 FS 28 File Separator	054 , 44	074 < 60	0114 L 76	0134 \ 92	0154 l 108	0174 | 124
D	015 CR 13 Carriage Return	035 GS 29 Group Separator	055 - 45	075 = 61	0115 M 77	0135] 93	0155 m 109	0175 } 125
E	016 SO 14 Shift Out	036 RS 30 Record Separator	056 . 46	076 > 62	0116 N 78	0136 ^ 94	0156 n 110	0176 ~ 126
F	017 SI 15 Shift In	037 US 31 Unit Separator	057 / 47	077 ? 63	0117 O 79	0137 _ 95	0157 o 111	0177 DEL 127 Rubout

CTRL