PICmicro MCU C®

An introduction to programming
The Microchip PIC in CCS C

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Preface

Thanks go to Rodger Richey of Microchip Technology Inc. for the use of this notes on C for the PICmicro® MCU, Mark at CCS, Inc. and Val Bellamy for proofreading this book.

This book is dedicated to my wise June and daughter Emma.

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Introduction

Why use C?

The C language was development at Bell Labs in the early 1970's by Dennis Ritchie and Brian Kernighan. One of the first platforms for implementation was the PDP-11 running under a UNIX environment.
Since its introduction, it has evolved and been standardized throughout the computing industry as an established development language. The PC has become a cost effective development platform using C++ or other favored versions of the ANSI standard.

C is a portable language intended to have minimal modification when transferring programs from one computer to another. This is fine when working with PC's and mainframes, but Microcontrollers and Microprocessors are different breed. The main program flow will basically remain unchanged, while the various setup and port/peripheral control will be micro specific. An example of this is the port direction registers on a PICmicro® MCU are set 1=Input 0=Output, whereas the H8 is 0=Input and 1=Output.

The use of C in Microcontroller applications has been brought about by manufacturers providing larger program and RAM memory areas in addition to faster operating speeds.

An example quoted to me – as a non believer – was: to create a stopclock function would take 2/3 days in C or 2 weeks in assembler.
'Ah' I hear you say as you rush to buy a C compiler – why do we bother to write in assembler? It comes down to code efficiency – a program written in assembler is typically 80% the size of a C version. Fine on the larger program memory sized devices but not so efficient on smaller devices. You pay the money and take you PIC!!

PC Based vs. PICmicro® MCU Based Program Development

Engineers starting development on PC based products have the luxury of basic hardware pre-wired (i.e., keyboard, processor, memory, I/O, printer and visual display (screen)). The product development then comes down to writing the software and debugging the errors.

Those embarking on a PIC based design have to create all the interfaces to the outside world in the form of input and output hardware.
A PC programmer could write the message "**Hello World**" and after compiling, have the message displayed on the screen. The PIC programmer would have to build an RS232 interface, set up the comm. port within the PIC, and attach the development board to a comm. Port on a PC to enable the message to be viewed.

'Why bother' I hear you say (and so did I). It comes down to portability of the end product. If we could get the whole of a PC in a 40 pin DIL package (including monitor and keyboard) we would use it; today's miniaturization does not reach these limits. We will continue to use Microcontrollers like the PIC for low cost and portable applications.

The development tools for PIC based designs offer the developer basically the same facilities as the PC based development with the exception of the graphics libraries.

Product Development

Product development is a combination of luck and experience. Some of the simplest tasks can take a long time to develop and to perfect in proportion to the overall product – so be warned where tight timescales are involved.

To design a product one needs: time – peace and quiet – a logical mind and most important of all a full understanding of the requirements.
I find the easiest way to begin any development is to start with a clean sheet of paper together with the specification or idea.

Start by drawing out a number of possible solutions and examine each to try to find the simplest and most reliable option. Do not discard the other ideas at this stage as there are possibly some good thoughts there.

Draw out a flow chart, block diagram, I/O connection plan or any suitable drawing to get started.

Build up a prototype board or hardware mimic board with all the I/O

configured. Don't forget I/O pins can be swapped to make board layout easier at a later date – usually wit minimal modification to the software.

Then start writing code – in testable blocks – and gradually build up your program. This saves trying to debug 2000 lines of code in one go!

If this is your first project – THEN KEEP IT SIMPLE – try switching an LED or two on and off from push buttons to get familiar with the instructions, assembly technique and debugging before attempting a mammoth project.

Build up the program in simple stages – testing as you go. Rework your flowchart to keep it up to date.

The Idea

An idea is born – maybe by yourself in true EUREKA style or by someone else having a need for a project – the basic concept is the same.

Before the design process starts, the basic terminology needs to be understood – like learning a new language. So in the case of Microcontroller designs based on the PICmicro® MCU, the PIC language (instruction set, terms and development kit) needs to be thoroughly understood before the design can commence.

Now let's get started with the general terms, some facts about the PIC and the difference between Microprocessor and Microcontroller based systems.

Terminology

Let's start with some basic terminology used.

Microcontroller A lump of plastic, metal and purified sand, which without any software, does nothing. When software controls a microcontroller, it has almost unlimited applications.

I/O A connection pin to the outside world which can be configured as input or output. I/O is needed in most cases to allow the microcontroller to communicate, control or read information.

Software The information that the Microcontroller needs to operate or run. This needs to be free of bugs and errors for a successful application or product. Software can be written in a variety of languages such as C, Pascal or Assembler (one level up from writing your software in binary).

Hardware The Microcontroller, memory, interface components, power supplies, signal conditioning circuits and all the components – connected to it

to make it work and interface to the outside world.
Another way of looking at (especially when it does not work) is that you can kick hardware.

Simulator The MPLAB® development environment has its own built-in simulator which allows access to some of the internal operation of the microcontroller. This is a good way of testing your designs if you know when events occur. If an event occurs 'somewhere about there', you might find the simulator restrictive. Full trace, step and debug facilities are, however, available. Another product for 16C5x development is the SIM ICE – a hardware simulator offering some of the ICE features but at a fraction of the cost.

In Circuit Emulator (ICEPIC or PICmicro® MCU MASTER) a very useful piece of equipment connected between your PC and the socket where the Microcontroller will reside. It enables the software to be run on the PC but look like a Microcontroller at the circuit board end. The ICE allows you to step through a program, watch what happens within the micro and how it communicates with the outside world.

Programmer A unit to enable the program to be loaded into the microcontroller's memory which allows it to run without the aid of an ICE. They come in all shapes and sizes and costs vary. Both the PICSTART PLUS and PROMATE II from Microchip connect to the serial port.

Source File A program written in a language the assembler and you understand. The source file has to be processed before the Microcontroller will understand it.

Assembler / Compiler A software package which converts the Source file into an Object file. Error checking is built in, a heavily used feature in debugging a program as errors are flagged up during the assembly process. MPASM is the latest assembler from Microchip handling all the PIC family.

Object File This is s file produced by the Assembler / Compiler and is in a form which the programmer, simulator or ICE understands to enable it to perform its function. File extension is .OBJ or .HEX depending on the assembler directive.

List File This is a file created by the Assembler / Compiler and contains all the instructions from the Source file together with their hexadecimal values alongside and comments you have written. This is the most useful file to examine when trying to debug the program as you have a greater chance of following what is happening within the software than the Source file listing. The file extension is .LST

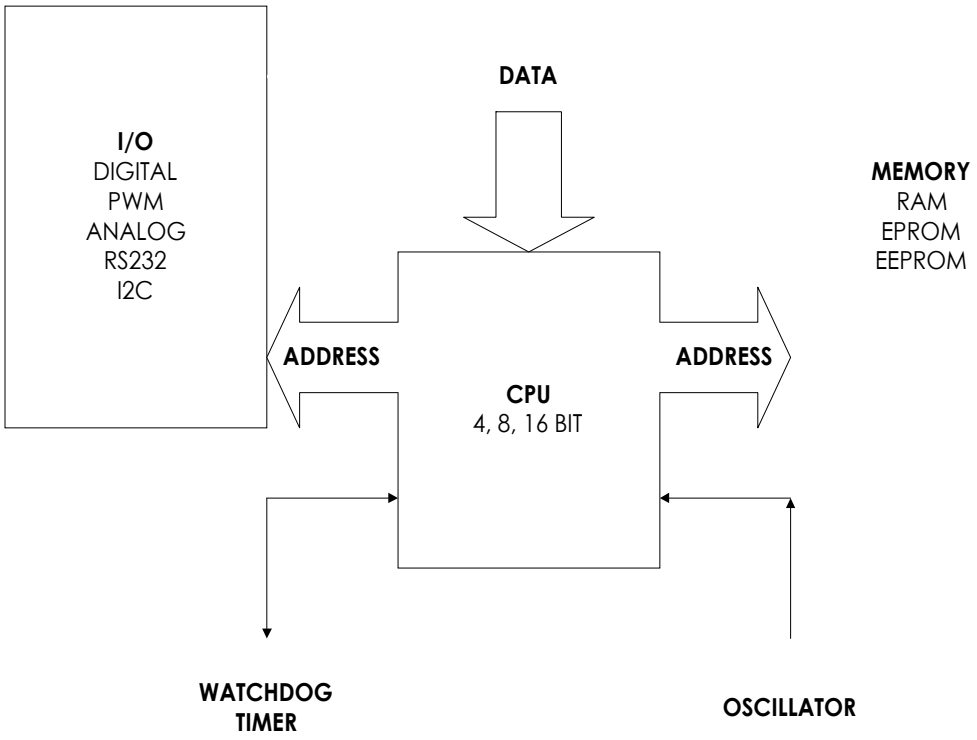
Other Files The error file (.ERR) contains a list of errors but does not give any indication as to their origin. The .COD file is used by the emulator.

Bugs Errors created free of charge by you. These range from simpel typin errus to incorrect use of the software language syntax errors. Most of these bugs will be found by the compiler and shown up in a .LST file, others will have to be sought and corrected by trial and error.

Microprocessor

A microprocessor or digital computer is made up of three basic sections: CPU, I/O and Memory – with the addition of some support circuitry.

Each section can vary in complexity from the basic to all bells and whistles.



TYPICAL MICROPROCESSOR SYSTEM

Taking each one in turn:

Input/output (I/O) can comprise digital, analog and special functions and is the section which communicates with the outside world.

The central processor unit (CPU) is the heart of the system and can work in 4, 8, or 16 bit data formats to perform the calculations and data manipulation.

The memory can be RAM, ROM, EPROM, EEPROM or any combination of these and is used to store the program and data.

An oscillator is required to drive the microprocessor. Its function is to clock data and instructions into the CPU, compute the results and then output the information. The oscillator can be made from discrete components or be a ready made module.

Other circuitry found associated with the microprocessor are the watch dog timer – to help prevent system latch up, buffering for address and data busses to allow a number of chips to be connected together without deteriorating the logic levels and decode logic for address and I/O to select one of a number of circuits connected on the same bus.

It is normal to refer to a Microprocessor as a product which is mainly the CPU area of the system. The I/O and memory would be formed from separate chips and require a Data Bus, Address Bus and Address Decoding to enable correct operation.

Microcontrollers

The PICmicro® MCU, on the other hand, is a Microcontroller and has all the CPU, memory, oscillator, watchdog and I/O incorporated within the same chip. This saves space, design time and external peripheral timing and compatibility problems, but in some circumstances can limit the design to a set memory size and I/O capabilities.

The PIC family of microcontrollers offers a wide range of I/O, memory and special functions to meet most requirements of the development engineer.

You will find many general books on library shelves exploring the design of microcontrollers, microprocessors and computers, so the subject will not be expanded or duplicated here other than to explain the basic differences.

Why use the PIC

Code Efficiency The PIC is an 8 bit Microcontroller based on the Harvard architecture – which means there are separate internal busses for memory and data. The throughput rate is therefore increased due to simultaneous access to both data and program memory. Conventional microcontrollers tend to have one internal bus handling both data and program. This slows operation down by at least a factor of 2 when compared to the PICmicro® MCU.

Safety All the instructions fit into a 12 or 14 bit program memory word. There is no likelihood of the software jumping onto the DATA section of a program and trying to execute DATA as instructions. This can occur in a non Harvard architecture microcontroller using 8-bit busses.

Instruction Set There are 33 instructions you have to learn in order to write software for the 16C5x family and 14 bits wide for the 16Cxx family. Each instruction, with the exception of CALL, GOTO or bit testing instructions (BTFSS, INCFSZ), executes in one cycle.

Speed The PIC has an internal divide by 4 connected between the oscillator

and the internal clock bus. This makes instruction time easy to calculate, especially if you use a 4 MHz crystal. Each instruction cycle then works out at 1 uS. The PIC is a very fast micro to work with e.g. a 20MHz crystal steps through a program at 5 million instructions per second! – almost twice the speed of a 386SX 33!

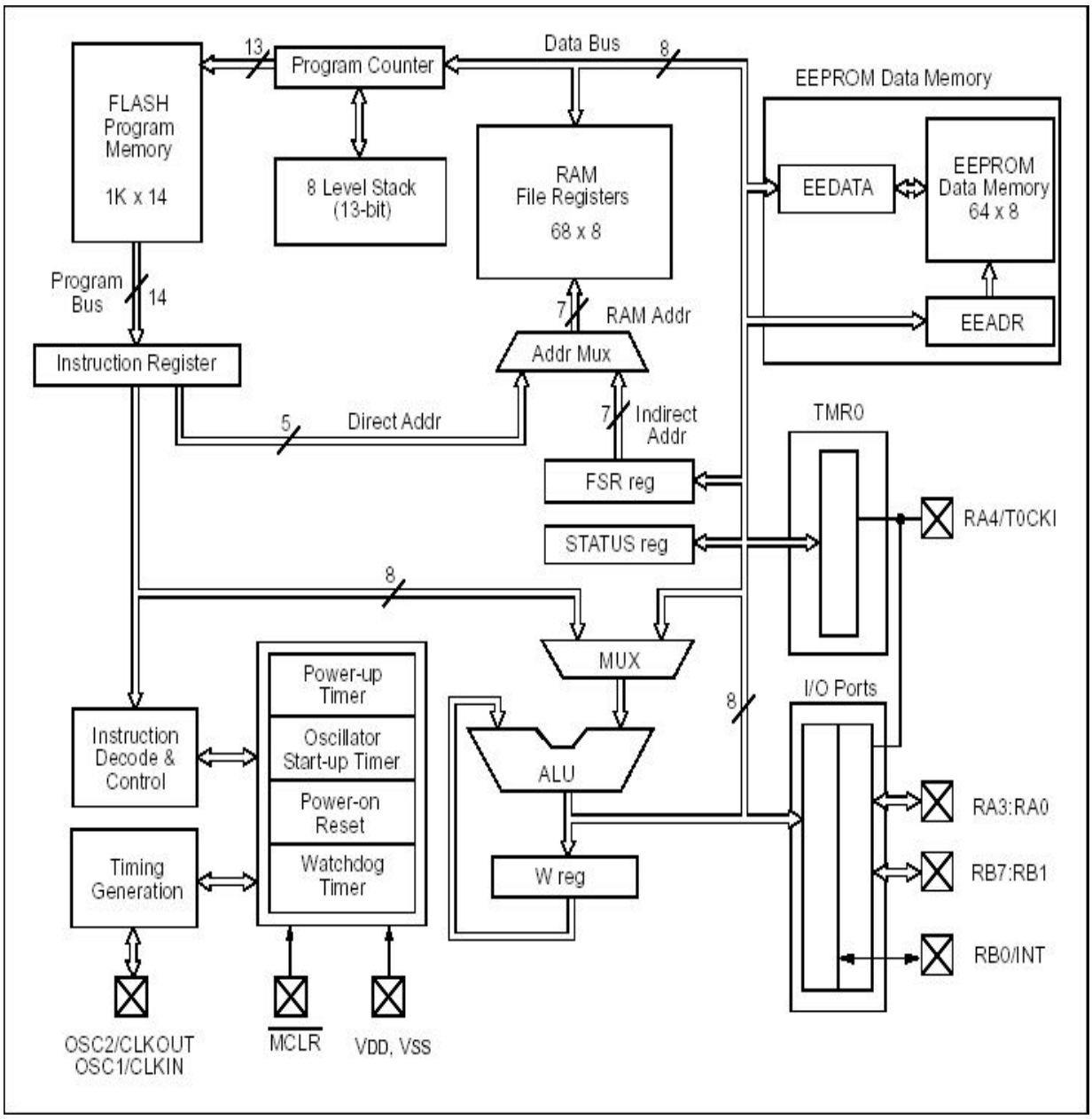
Static Operation The PIC is a fully static microprocessor; in other words, if you stop the clock, all the register contends are maintained. In practice you would not actually do this, you would place the PIC into a Sleep mode – this stops the clock and sets up various flags within the PIC to allow you to know what state it was in before the Sleep. In Sleep, the PIC takes only its standby current which can be less the 1uA.

Drive Capability The PIC has a high output drive capability and can directly drive LEDs and triacs etc. Any I/O pin can sink 25mA or 100mA for the whole device.

Options A range of speed, temperature, package, I/O lines, timer functions, serial comms, A/D and memory sizes is available from the PIC family to suit virtually all your requirements.

Versatility The PIC is a versatile micro and in volume is a low cost solution to replace even a few logic gates; especially where space is at a premium.

PIC FUNCTION BLOCK DIAGRAM



PIC16F84A(14Bit) BLOCK DIAGRAM

Security The PICmicro® MCU has a code protection facility which is one of the best in the industry. Once the protection bit has been programmed, the contents of the program memory cannot be read out in a way that the program code can be reconstructed.

Development The PIC is available in windowed form for development and OTP (one time programmable) for production. The tools for development are readily available and are very affordable even for the home enthusiast.

Trying and Testing Code

Getting to grips with C can be a daunting task and the initial outlay for a C compiler, In Circuit Emulator and necessary hardware for the PIC can be prohibitive at the evaluation stage of a project. The C compiler supplied on this disk was obtained from the Internet and is included as a test bed for code learning. Basic code examples and functions can be tried, tested and viewed before delving into PIC specific C compilers which handle I/O etc.

C Coding Standards

Program writing is like building a house – if the foundations are firm, the rest of the code will stack up. If the foundations are weak, the code will fall over at some point or other. The following recommendations were taken from a C++ Standards document and have been adapted for the PIC.

Names – make them fit their function
Names are the heart of programming so make a name appropriate to its function and what it's used for in the program.
Use mixed case names to improve the readability

ErrorCheck is easier than ERRORCHECK

Prefix names with a lowercase letter of their type, again to improve readability:

g	Global	**gLog**;
r	Reference	**rStatus();**
s	Static	**sValueIn;**

Braces{}
Braces or curly brackets can be used in the traditional UNIX way

```
if (condition) {
…….
}
```

or the preferred method which is easier to read

```
if (condition)
```

```
{
…….
}
```

Tabs and Indentation
Use spaces in place of tabs as the normal tab setting of 8 soon uses up the page width. Indent text only as needed to make the software readable. Also, tabs set in one editor may not be the same settings in another – make the code portable.

Line Length
Keep line lengths to 78 characters for compatibility between monitors and printers.

Else If Formatting
Include an extra Else statement to catch any conditions not covered by the preceding if's

```
if (condition)
{
}
else if (condition)
{
}
else
{
……..        /* catches anything else not covered above */
}
```

Condition Format
Where the compiler allows it, always put the constant on the left hand side of an equality / inequality comparison, If one = is omitted, the compiler will find the error for you. The value is also placed in a prominent place.

```
if ( 6 == ErrorNum) …
```

Initialize All Variables
Set all variables to a known values to prevent 'floating or random conditions'

```
int a=6, b=0;
```

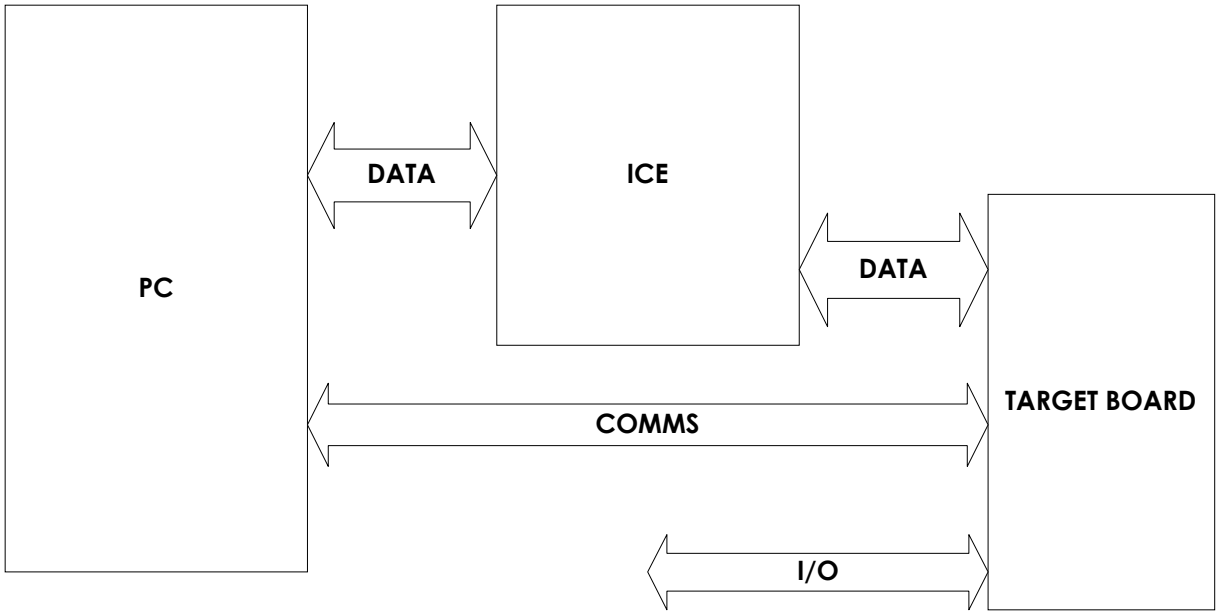
Comments
Comments create the other half of the story you are writing. You know how your program operates today but in two weeks or two years will you remember, or could someone else follow your program as it stands today? Use comments to mark areas where further work needs to be done, errors to be debugged or future enhancements to the product.

Basics

All computer programs have a start. The start point in Microcontrollers is the reset vector. The 14 bit core (PIC16Cxx family) reset at 00h, the 12 bit core (PIC16C5x and 12C50x) reset at the highest point in memory – 1FFh, 3FFh, 7FFh.

The finish point would be where the program stops if run only once e.g. a routine to set up a baud rate for communications. Other programs will loop back towards the start point such as traffic light control. One of the most widely used first programming examples in high level languages like Basic or C is printing 'Hello World' on the computer screen.

Using C and a PC is straightforward as the screen, keyboard and processor are all interconnected. The basic hooks need to be placed in the program to link the program to the peripherals. When developing a program for the PICmicro® MCU or any microprocessor / microcontroller system, you need not only the software hooks but also the physical hardware to connect the micro to the outside world. Such a system is shown below.



Using such a layout enables basic I/O and comms to be evaluated, tested and debugged. The use of the ICE, through not essential, speeds up the development costs and engineer's headaches. The initial investment may appear excessive when facing the start of a project, but time saved in developing and debugging is soon outstripped.

The hardware needed to evaluated a design can be a custom made PCB, protoboard or an off the shelf development board such as our PICmicro® MCU Millennium board contains (someone had to do one!). The Millennium board contains all the basic hardware to enable commencement of most designs while keeping the initial outlay to a minimum.

Assemble the following hardware in whichever format you prefer. You WILL need a PIC programmer such as the PICSTART Plus as a minimal outlay in addition to the C compiler.

A simple program I use when teaching engineers about the PIC is the 'Press button – turn on LED'. Start with a simple code example – not 2000 lines of code!
In Assembler this would be:-

```
main      btfss     porta,switch     ;test for switch closure
          got       main             ;loop until pressed
          bsf       portb,led        ;turn on led
lp1       btfsc     porta,switch     ;test for switch open
          goto      lp1              ;loop until released
          bcf       portb,led        ;turn off led
          goto      main             ;loop back to start
```

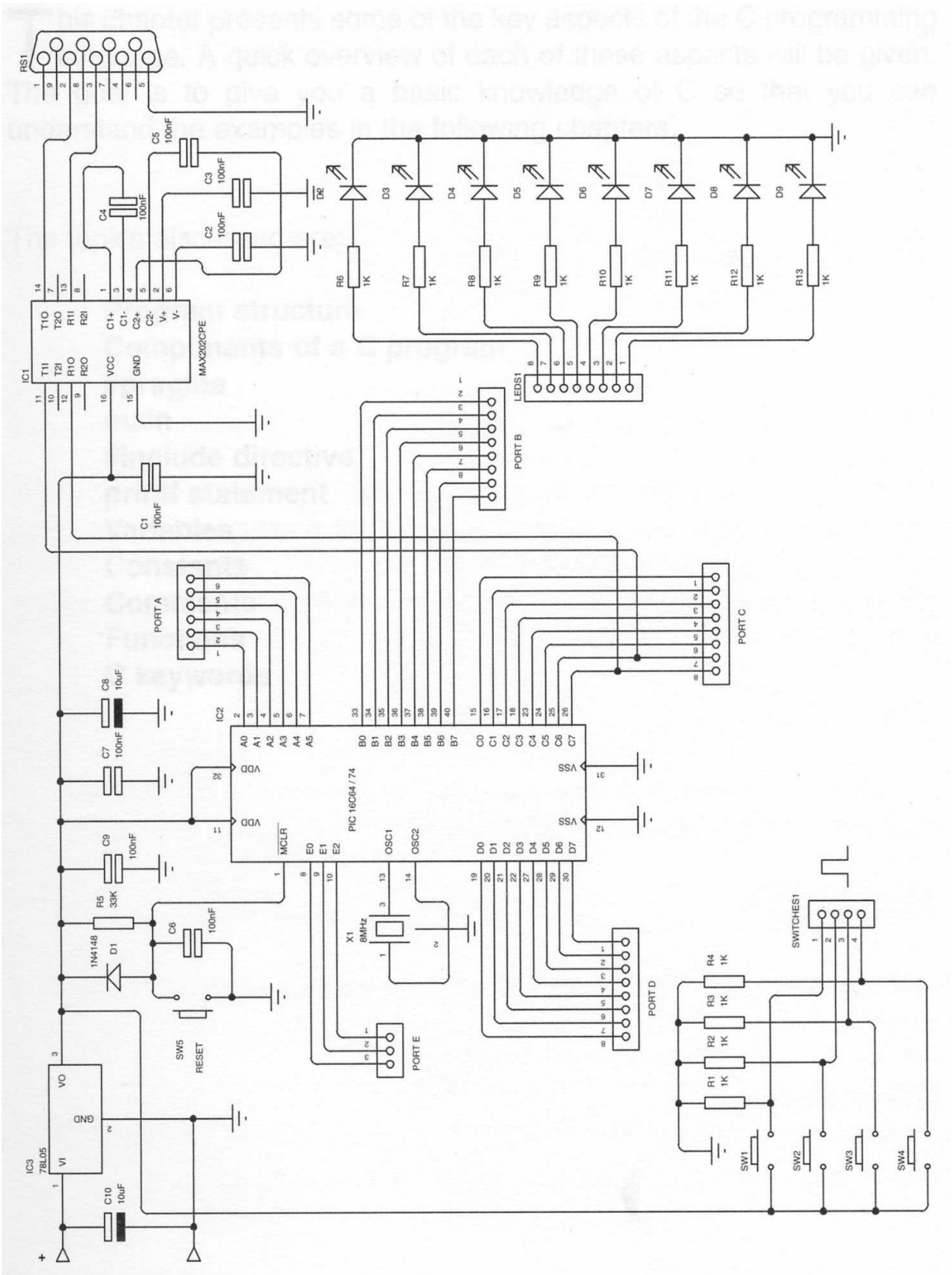
In C this converts to

```
main()
{
   set_tris_b(0x00);                  //set port b as outputs
   while(true)
   {
      if (input(PIN_A0))              //test for switch closure
         output_high(PIN_B0);         //if closed turn on led
      else
         output_low(PIN_B0);          //if open turn off led
   }
}
```

When assembled, the code looks like this:-

```
main()
{
   set_tris_b(0x00);                  0007     MOVLW    00
                                      0008     TRIS     6
   while(true)
   {
      if (input(PIN_A0))              0009     BTFSS    05,0
                                      000A     GOTO     00D
         output_high(PIN_B0);
                                      000B     BSF      06,0
      else
                                      000C     GOTO     00E
         output_low(PIN_B0);
                                      000D     BCF      06,0
   }
                                      000E     GOTO     009
}
```

As you can see, the compiled version takes more words in memory – 14 in C as opposed to 9 in Assembler. This is not a fair example on code but as programs get larger, the more efficient C becomes in code usage.


RS1
C5 100nF
C3 100nF
C4 100nF
C2 100nF
D2
D3
D4
D5
D6
D7
D8
D9
R6 1K
R7 1K
R8 1K
R9 1K
R10 1K
R11 1K
R12 1K
R13 1K
IC1
MAX202CPE
T1O T2O R1I R2I C1+ C1- C2+ C2- V+ V-
T1I T2I R1O R2O VCC GND
LEDS1
PORT B
C1 100nF
PORT A
PORT C
C8 10uF
C7 100nF
IC2
PIC 16C64 / 74
A0 A1 A2 A3 A4 A5
B0 B1 B2 B3 B4 B5 B6 B7
C0 C1 C2 C3 C4 C5 C6 C7
VDD VDD VSS VSS
MCLR E0 E1 E2 OSC1 OSC2
D0 D1 D2 D3 D4 D5 D6 D7
C9 100nF
R5 33K
C6 100nF
D1 1N4148
X1 8MHz
SW5 RESET
PORT E
PORT D
SWITCHES1
R4 1K
R3 1K
R2 1K
R1 1K
SW1
SW2
SW3
SW4
IC3 78L05
VI GND VO
C10 10uF
+

C Fundamentals

This chapter presents some of the key aspects of the C programming language
A quick overview of each of these aspects will be given.
The goal is to give you a basic knowledge of C so that you can understand the examples in the following chapters.

The topics discussed are:

Program structure
Components of a C program
#pragma
main
#include directive
printf statement
Variables
Constants
Comments
Functions
C keywords

1.1 The Structure of C Programs

All C program contain preprocessor directives, declarations, definitions, expressions, statements and functions.

Preprocessor directive
A preprocessor directive is a command to the C preprocessor (which is automatically invoked as the first step in compiling a program). The two most common preprocessor directives are the **#define** directive, which substitutes text for the specified identifier, and the **#include** directive, which includes the text of an external file into a program.

Declaration
A declaration establishes the names and attributes of variables, functions, and types used in the program. Global variables are declared outside functions and are visible from the end of the declaration to the end of the file. A local variable is declared inside a function and is visible form the end of the declaration to the end of the function.

Definition
A definition establishes the contents of a variable or function. A definition also allocates the storage needed for variables and functions.

Expression
An expression is a combination of operators and operands that yields a single value.

Statement
Statements control the flow or order of program execution in a C program.

Function
A function is a collection of declarations, definitions, expressions, and statements that performs a specific task. Braces enclose the body of a function. Functions may not be nested in C.

`main` Function

All C programs must contain a function named **`main`** where program execution begins. The braces that enclose the **`main`** function define the beginning and ending point of the program.

Example: General C program structure

```
#include <stdio.h>          /* preprocessor directive */
#define PI 3.142            /* include standard C header file */
float area;                 /* global declaration */
int square (int r);         /* prototype declaration */

main()
{                           /* beginning of main function */
   int radius_squared;      /* local declaration */
   int radius = 3;          /* declaration and initialization */
   radius_squared = square (radius);
                            /* pass a value to a function */
   area = PI * radius_squared;
                            /* assignment statement */
   printf("Area is %6.4f square units\n",area);
}                           /* end of main function & program */

square(int r)               /* function head */
{
   int r_squared;           /* declarations here are known */
                            /* only to square */
   r_squared = r * r;
   return(r_squared);       /* return value to calling statement
*/
}
```

1.2 Components of a C program

All C programs contain essential components such as statements and functions. Statements are the parts of the program that actually perform operations. All C programs contain one or more functions. Functions are subroutines, each of which contains one or more statements and can be called upon by other parts of the program. When writing programs, indentations, blank lines and comments, improve the readability – not only for yourself at a later date, but also for those who bravely follow on. The following example shows some of the required parts of a C program.

```
#include <stdio.h>
/* My first C program */
main()
{
   printf("Hello world!");
```

```
}
```

The statement **`#include <stdio.h>`** tells the compiler to include the source code from the file 'stdio.h' into the program.

The extension .h stands for header file. A header file contains information about standard functions that are used in the program. The header file **`stdio.h`** which is called the **ST**andar**D I**nput and **O**utput header file, contains most of the input and output functions. It is necessary to use only the include files that pertain to the standard library functions in your program.

`/* My first C program /` is a comment in C. Tradional comments are preceded by a /* and end with a */. Newer style comments begin with // and go to the end of the line. Comments are ignored by the compiler and therefore do not affect the speed or length of the compiled code.

All C programs must have a **`main()`** function. This is the entry point into the program. All functions have the same format which is:

```
FunctionName()
{
    code
}
```

Statements within a function are executed sequentially, beginning with the open curly brace and ending with the closed curly brace.

The curly braces { and } show the beginning and ending of blocks of code in C.

Finally, the statement **`printf("Hello world!");`** presents a typical C statement. Almost all C statements end with a semicolon (**`;`**). The end-of-line charater is not recognized by C as a line terminator.
Therefore, there are no constraints on the position of statements within a line or on the number of statements on a line.

All statements have a semi-colon (`;`) at the end to inform the compiler it has reached the end of the statement and to separate it from the next statement. Failure to include this will generally flag an error in the NEXT line. The **`if`** statement is a compound statement and the **`;`** needs to be at the end of the compound statement:

```
if (ThisIsTrue)
    DoThisFunction();
```

1.3 #pragma

The pragma command instructs the compiler to perform a particular action at the compile time such as specifying the PICmicro® MUC being used or the file format generated.

```
#pragma   device    PIC16C54
```

In CCS C the pragma is optional so the following is accepted:

```
#device   pic16c54
```

1.4 main()

Every program must have a **main** function which can appear only once. No parameters can be placed in the ( ) brackets which follow. The keyword **void** may optionally appear between the (and) to clarity there are no parameters. As **main** is classed as a function, all code which follows must be placed within a pair of braces { } or curly brackets.

```
main()
{
   body of program
}
```

1.5 #include

The header file, (denoted by a .h extension) contains information about library functions such as what argument(s) the function accepts and what argument (s) the function returns or the location of PICmicro® MCU registers for a specific PIC

```
#include <16C54H>
```

This information is used by the compiler to link all the hardware specifics and source programs together.

```
#include <16c71.h>
#include <ctype.h>
#use rs232(baud=9600,xmit=PIN_B0,rcv=PIN_B1)
main()
{
   printf("Enter characters:");
   while(TRUE)
      putc(toupper(getc()));
}
```

The definitions **PIN_B0** and **PIN_B1** are found in the header file 16C71.H. The function **toupper** is found in the header file **CTYPE.H**. Both of these header files

must be used in the program so the compiler has essential information about the functions that you are using. Note that many C compilers also require header files for I/O functions like **printf** and **putc**. These are built-in functions for the PICmicr® MCU that are pulled in via the **#use rs232** and do not require a separate header file.

Angled brakets

```
#include <thisfile.h>
```

tell the preprocessor to look in predefined include file directories for the file, while the quote marks tell the preprocessor to look in the current directory first.

```
#include "thatfile.h"
```

You have probably noticed that the **#include** directive does not have a semicolon at the end. The reason for this is that the **#include** directive is not a C statement, but instead is a preprocessor directive to the compiler.
The whole of the **include** file is inserted into the source file at the compile stage.

1.6 printf Function

The **printf** function is a standard library function which allows the programmer to send printable information. The general format for a **printf()** statement is:

```
printf("control_string", argument_list);
```

A **control_string** is a string with double quotes at each end. Inside this string, any combination of letters, numbers and symbols can be used. Special symbols call format specifiers are denoted with a %. The **control_string** must always be present in the **printf()** function. An **argument_list** may not be required if there are no format specifiers in the format string. The **argument_list** can be composed of constants and variables. The following two examples show **printf()** statements using a constant and then a variable.

```
printf("Hello world!");
printf("Microchip® is #%d!",1);
```

The format specifier (%d) is dependent on the type of data being displayed. The table below shows all of the format specifiers in C and the data types they affect.

Format Specifiers **printf()**

%c	**single character**

```
%d      signed decimal interger
%f      floating point (decimal notation – must include)
%e      floating point (exponential or scientific notation)
%u      unsigned decimal integer
%x      unsigned hexadecimal integer (lower case)
%X      unsigned hexadecimal integer (upper case)
l       prefix used with %d, %u, %x to specify long integer
```

NOTE: A 0 (zero) following a % character within a format string forces leading zeros to be printed out. The number following specifies the width of the printed field.

```
printf("The Hex of decimal 12 is %02x\n",12);
```

This would be print out as:

```
The Hex of decimal 12 is 0c
```

Escape Sequences

```
\n      newline                 \t      horizontal tab
\r      carriage return         \f      formfeed
\'      single quote            \"      double quote
\\      backslash               %%      percent sign
\?      question mark           \b      backspace
\0      null character          \v      vertical tab
\xhhh   insert HEX code hhh
```

The format specification can also be shown as %[flags][width][.precision], so in a previous example the line:

```
printf("Area is %6.4f square units\n",area);
```

will print out the value **area** in a field width of 6, with a precision of 4 decimal places.

By default the printf output goes out the last defined RS232 port. The output, however, can be directed to anything defining your own output function. For example:

```
void lcd_putc(char c)
{
    // Insert code to output one
    // character to the LCD here
}
printf(lcd_putc, "value is %u", value);
```

1.7 Variables

A variable is a name for a specific memory location. This memory location can hold various values depending on how the variable was declared. In C, all variables must be declared before they are used. A variable declaration tells the compiler what type of variable is being used. All variable declarations are statements in C and therefore must be terminated with a semicolon.

Some basic data type that C supports are **char**, **int**, **float**, and **long**. The general format for declaring a variable is:

```
type variable_name;
```

An example of declaring a variable is **char ch;**. The compiler would interpret this statement as the variable **ch** is declared as a char (8-bit unsigned integer).

1.8 Constants

A constants is a fixed value which cannot be changed by the program.
For example, 25 is a constant. Integer constants are specified without any fractional components, such as –100 or 40. Floating point constants require the decimal point followed by the number's fractional component. The number 456.75 is a floating point constant. Character constants are enclosed between single quotes such as 'A' or '&'.

When the compiler encounters a constant in your program, it must decide what type of constant it is. The C compiler will, by default, fit the constant into the smallest compatible data type that will hold it. So 15 is an **int** and 64000 is an **unsigned**.
A constant can be declared using the **#define** statement.

```
#define <label> value
```

The **<label>** defines the name you will use throughout your program, **value** is the value you are assigning to **<label>**.

```
#define TRUE 1
#define pi 3.14159265359
```

C allow you to specify constants in hexadecimal and octal formats. Hexadecimal constants must have the prefix '0x'. For example 0xA4 is a valid hexadecimal constant. In addition to numeric constants, C supports string constants. String constants are a set of characters enclosed within double quotes.

Constants defined with **#define** are textual replacements performed before the code is compiled in a stage called pre-processing. Directives that start with

are called pre-processor directives. You can **`#define`** any text. For example:

```
#define NOT_OLD (AGE<65)
          .
          .
          .
          .
          .
if NOT_OLD
   printf("YOUNG");
```

`#define` data is not stored in memory, it is resolved at compile time.
To save constants in the chip **ROM**, use the **`const`** keyword in a variable declaration. For example:

```
char const id[5]={"1234"};
```

We use five locations to hold the string because the string should be terminated within the null (\0) character.

1.9 Comments

Comments are used to document the meaning and operation of the source code. All comments ate ignored by the compiler. A comment can be placed anywhere in the program except for the middle of a C keyword, function name, or variable name. Comments can be many lines long and may also be used to temporarily remove a line of code. Finally, comments cannot be nested.

Comments have two formats. The first format is used by all C compilers and is

```
/* This is a comment */
```

The second format is supported by most compilers and is

```
// This is a comment
```

EXERCISE: Which of the following comments is valid? invalid?

```
/* My comment is very short */

/* My comment is very, very, very, very, very, very, very,
very, very, very long and is valid */

/* This comment /* looks */ ok, but is invalid */
```

1.10 Functions

Functions are the basic building blocks of a C program. All C programs contain at least one function, **`main()`**. Most programs that you will write will contain many functions. The format for a C program with many functions is:

```
main()
{
    function1()
    {
    }
    function2()
    {
    }
}
```

`main()` is the first function called when the program is executed. The other functions, **`function1()`** and **`function2()`**, can be called by any function in the program.

Traditionally **`main()`** is not called by any other function, however, there are no restrictions in C.

The following is an example of two functions in C.

```
main()
{
    printf("I ");
    function1();
    printf("c.");
}
function1()
{
    printf("like ");
}
```

One reminder when writing your own functions is that when the closed curly brace of a function is reached, the program will start executing code one line after the point at which the function was originally called. See also section 3.1.

1.11 Macros

`#define` is a powerful directive as illustrated in the previous section. C allows defines to have parameters making them even more powerful. When parameters are used it is called a macro. Macros are used to enhance readability or to save typing. A simple macro:

```
#define var(x,v) unsigned int x=v;
var(a,1)
var(b,2)
var(c,3)
```

is the same as:

```
unsigned int a=1;
unsigned int b=2;
unsigned int c=3;
```

Another example that will be more meaningful after reading the expressions chapter:

```
#define MAX(A,B) (A>B)?A:B)
z=MAX(,y);    // z will contain the larger value x or y
```

1.12 Conditional compilation

C has some special pre-processor directives that allow sections of code to be included or excluded from compilation based on compile time settings. Consider the following example:

```
#define HW_VERSION 5
#if HW_VERSION>3
   output_high(PIN_B0);
#else
   output_high(PIN_B0);
#endif
```

The above will compile only one line depending on the setting of HW_VERSION. There may be dozens of these **`#if`**'s in a file and the same code could be compiled for different hardware version just by changing one constant. The **`#if`** is evaluated and finished when the code is compiled unlike a normal **`if`** that is evaluated when a program runs.
`#ifdef` simply checks to see if an ID was **`#defined.`**
Example:

```
#define DEBUG
#ifdef DEBUG
   printf("ENTERING FUCT X");
#endif
```

In this example all the debugging lines in the program can be eliminated from the compilation by removing or commenting on the one **`#define`** line.

1.13 Hardware Compatibility

The compiler needs to know about the hardware so the code can be compiled correctly. A typical program begins as follows:

```
#include <16c74.h>
#fuses hs,nowdt
#use delay(clock=800000)
```

The first line included device specific `#define` such as the pin names. The second line sets the PICmicro® MCU fuses. In this case the high speed oscillator and no watch dog timer. The last line tells the compiler what the oscillator speed is. The following are some other example lines:

```
#use rs232(buad=9600,xmit=PIN_C6,rcv=PIN_C7)
#use i2c(master,scl=PIN_B6,sda=PIN_B7)
```

The example program in this book do not show these hardware defining lines. These are required to compile and RCW these programs.

In addition, C variables may be created and mapped to hardware registers. These variables may be bits or bytes. After they are defined, they may be used in a program as with any other variable. Examples:

```
#bit carry=3.0
#byte portb=6
#byte intcon=11
```

1.14 C Keywords

The ANSI C standard defines 32 keywords for use in the C language. In C, certain words are reserved for use by the compiler to define data types or for use in loops. All C keywords must be in lowercase for the compiler to recognize them. Typically, many C compilers will add several additional keywords that take advantage of the processor's architecture.

The following is a list of the keywords which are reserved from use as variable names.

auto	**double**	**int**	**struct**
break	**else**	**long**	**switch**
case	**enum**	**register**	**typedef**
char	**extern**	**return**	**union**
const	**float**	**short**	**unsigned**
continue	**for**	**signed**	**void**
default	**goto**	**sizeof**	**volatile**
do	**if**	**static**	**while**

EXERCISE:

1. Write a program that prints your name to the screen.
2. Write a program that declares one integer variable called year. This variable should be given the value of the current year and then, using a **`printf()`** statement, display the value of year on the screen. The result of your program should look like this: **`The year is 1998`**

Variables

An important aspect of the C language is how it stores data. This chapter will examine more closely how variables are used in C to Store data.

The topics discussed in this chapter are:

data type
declarations
assignments
data type ranges
type conversions

2.1 Data Types

The C programming language supports five basic data types and four type modifiers. The following table shows the meanings of the basic data types and type modifiers.

Type	meaning	Keywords
character	character data	**char**
integer	unsigned whole numbers	**int**
float	floating point numbers	**float**
double	double precision floating numbers	**double**
void	valueless	**void**
signed	positive or negative number	**signed**
unsigned	positive only number	**unsigned**
long	longer range of a number	**long**
short	shorter range of a number	**short**

Each of the data types represent a particular range of numbers, which can change depending on the modifier used. The next table shows the possible range of values for all the possible combinations of the basic data types and modifiers.

Type	Bit Width	Range
short	1	0 or 1
short int	1	0 or 1
int	8	0 to 255
char	8	0 to 255
unsigned	8	0 to 255
unsigned int	8	0 to 255
signed	8	-128 to 127
signed int	8	-128 to 127
long	16	0 to 65536
long int	16	0 to 65536
signed long	16	-32768 to 32767
float	32	3.4E-38 to 3.4E+38

NOTE: See individual C compiler documentation for actual data types and numerical range.

C allows a shorthand notation for the data types **unsigned int**, **short int**, and **long int**. Simply use the word **unsigned**, **short**, or **long** without the **int**. To make arithmetic operations easier for the CPU, C represents all negative numbers in the 2's complement format. To find the 2's complement of a number simply invert all the bits and add a 1 to the result. For example, to convert the signed number 29 into 2's complement:

```
00011101 =    29
11100010      invert all bits
       1      add 1
11100011 =    -29
```

Example of assigning a long value of 12000 to **variables a**. 12000 in hex is 2EE0. The following code extract assigns the lower word (E0) to register 11h and the upper word (2E) to 12h

```
long a = 12000;
main()
{
    0007:  MOVLW  E0
    0008:  MOVWF  11
    0009:  MOVLW  2E
    000A:  MOVWF  12
}
```

EXERCISE:
1. Write this statement in another way:

```
long int i;
```

2. To understand the difference between a signed number and an unsigned number, type in the following program. The unsigned integer 35000 is represented by –30536 in signed integer format.

```
main()
{
    int i;        /* signed integer */
    unsigned int u;  /* unsigned interger */
    u = 35000;
    i =u;
    printf("%d %u\n", i, u);
}
```

2.2 Variable Declaration

Variables can be declared in two basic places: inside a function or outside all functions. The variables are called local and global, respectively. Variables are declared in the following manner:

```
type variable_name;
```

Where **type** is one of C's valid data types and **variable_name** is the name of the variable.

Local variables (declared inside a function) can only be used by statements within the function where they are declared.

The value of a local variable cannot be accessed by functions statements outside of the function. The most import thing to remember about local variables is that they are created upon entry into the function and destroyed when the function is exited. Local variables must also be declared at the start of the function before the statements.

It is acceptable for local variables in different functions to have the same name. Consider the following example:

```
void f2(void)
{
    int count;
    for (count = 0 ; count < 10 ; count++)
        print("%d \n",count);
}

f1()
{
    int count;
    for (count=0; count<10; count++)
        f2();
}

main()
{
    f1();
    return 0;
}
```

This program will print the numbers 0 through 9 on the screen ten times. The operation of the program is not affected by a variable name **count** located in both functions.

Global variables, on the other hand, can be used by many different functions. Global variables must be declared before any functions that use them. Most importantly, global variables are not destroyed until the execution of the program is complete.

The following example shows how global variables are used.

```
int max;
f1()
{
    int i;
    for(i=0; i<max;i++)
    printf("%d ",i);
```

```
}

main()
{
    max=10;
    f1();
    return0;
}
```

In this example; both functions **main()** and **f1()** reference that variable max. The function **main()** assigns a value to max and the function **f1()** uses the value of max to control the **for** loop.

EXERCISE:

1. What are the main differences between local and global variables?
2. Both local and global variables may share the same name in C. Type in the following program.

```
int count;

f1()
{
    int count;
    count=100;
    printf("count in f1(): %d\n",count);
}

main()
{
    count=10;
    f1();
    printf("count in main(): %d\n",count);
    return 0;
}
```

In **main()** the reference to **count** is the global variable. In **f1()** the local variable **count** overrides the usage of the global variable.

2.3 Variable Assignment

Up to now we have only discussed how to declare a variable in a program and not really how to assign a value to it. Assignment of values to variables is simple:

```
variable_name = value;
```

Since a variable assignment is a statement, we have to include the semicolon at the end. An example of assigning the value 100 to the integer variable count is:

```
count = 100;
```

The value 100 is called a constant.

Variables values can be initialized at the same time as they are declared. This makes it easier and more reliable in setting the starting values in your program to know conditions. E.g.

```
int a =10, b = 0, c = 0x23;
```

Many different types of constants exist in C. A character constant is specified by enclosing the character in single quotes, such as **'M'**.
Whole numbers are used when assigning values to integer. Floating point numbers must use a value with a decimal point. For example, to tell C that the value 100 is a floating point value, use **100.0**.

A variable can also be assigned the value of another variable. The following program illustrates this assignment.

```
main()
{
    int i;
    int j;
    i=0;
    j=i;
}
```

EXERCISE:

1. Write a program that declares one integer variable called **count**. Give **count** a value of 100 and use a **printf()** statement to display the value. The output should look like this:

```
100 is the value of count
```

2. Write a program that declares three variables **char**, **float**, and **double** with variable names of **ch**, **f**, and **d**. Assign an **'R'** to the char, **50.5** to the float,

and **156.007** to the double. Display the value of these variables to the screen. The output should look like this:

```
ch is R
f is 50.5
d is 156.007
```

2.4 Enumeration

In C, it is possible to create a list of named integer constants. This declaration is called enumeration. The list of constants created with an enumeration can be used any place an integer can be used. The general form for creating an enumeration is:

```
enum name {enumeration list} variable(s);
```

The variable list is an optional item of an enumeration. Enumeration variables may contain only the values that are defined in the enumeration list. For example, in the statement

```
enum color_type {red,green,yellow} color;
```

the variable color can only be assigned the values **red**, **green**, or **yellow** **(i.e., color = red;)**.

The compiler will assign integer values to the enumeration list starting with 0 at the first entry. Each entry is one greater than the previous one. Therefore, in the above example **red** is **0**, **green** is **1** and **yellow** is **2**. This default value can be override by specifying a value for a constant. This example illustrates this technique.

```
enum color_type {red,gree=9,yellow} color;
```

This statement assigns **0** to **red**, **9** to **green** and **10** to **yellow**.

Once an enumeration is defined, the name can be used to create additional variables at other points in the program. For example, the variable **mycolor** can be created with the **colortype** enumeration by:

```
enum color_type mycolor;
```

The variable can also be tested against another one:

```
if (color==fruit)
// do something
```

Essentially, enumerations help to document code. Instead of assigning a value

to a variable, an enumeration van be used to clarity the meaning of the value.

EXERCISE:
1. Create an enumeration of the PIC17CXX family line.
2. Create an enumeration of currency from the lowest to highest denomination
3. Is the following fragment correct? Why/Why not?

```
enum {PIC16C51,PIC16C52,PIC16C53} device;
    device = PIC16C52;
    printf("First PIC was %s\n",device);
```

2.5 typedef

The **typedef** statement is used to define new types by the means of existing types. The format is:

```
typedef old_name new_name;
```

The new name can be used to declare variables. For instance, the following program uses the name **smallint** for the type signed **char**.

```
typedef signed char smallint;
main()
{
    smallint i;
    for(i=0;i<10;i++)
        printf("%d ",i);
}
```

When using a **typedef**, you must remember two key points: A **typedef** does not deactivate the original name or type, in the previous example **signed char** is still a valid type; several **typedef** statements can be used to create many new names for the same original type.

Typedefs are typically used for two reasons. The first is to create portable programs. If the program you are writing will be used on machines with 16-bit and 32-bit integer, you might want to ensure that only 16-bit integers are used. The program for 16-bit machines would use

```
typedef int myint;
```

To make all integers declared as **myint** 16-bits. Then, before compiling the program for the 32-bit computer, the **typedef** statement should be changed to

```
typedef short int myint;
```

So that all integers declared as **myint** are 16-bits.

The second reason to use **typedef** statements is to help you document your code. If your code contains many variables used to hold a count of some sort, you could use the following **typefef** statement to declare all your **counter** variables.

```
typedef int counter;
```

Someone reading your code would recognize that any variable declared as **counter** is used as a counter in the program.

EXERCISE:

1. Make a new name for **unsigned long** called UL. Use this **typed** in a short program that declares a variable using UL, assigns a value to it and displays the value to the screen.
2. Is the following segment of code valid?

```
typedef int height;
typedef height length;
typedef length depth;
depth d;
```

2.6 type Conversions

C allows you to mix different data types together in one expression. For example, the following is a valid code fragment:

```
char ch = '0';
int i = 15;
float f = 25.6;
```

The mixing of data types is governed by a strict set of conversion rules that tell the compiler how to resolve the differences. The first part of the rule set is a type promotion. The C compiler will automatically promote a **char** or **short int** in an expression to an **int** when the expression is evaluated. A type promotion is only valid during the evaluation of the expression; the variable itself does not become physically larger.

Now that the automatic type promotions have been completed, the C compiler will convert all variables in the expression up to the type of the largest variable. This task is done on an operation by operation basis. The following algorithm shows the type conversions:

IF an operand is a long double

THEN the second is converted to long double
ELSE IF an operand is a double
THEN the second is converted to double
ELSE IF an operand is a float
THEN the second is converted to float
ELSE IF an operand is an unsigned long
THEN an operand is a unsigned long
ELSE IF an operand is a long
THEN the second is converted to long
ELSE IF an operand is an unsigned
THEN the second is converted to unsigned

Let's take a look at the previous example and discover what type of promotions and conversions are taking place. First of all, **ch** is promoted to an **int**. The first operation is the multiplication of **ch** with **i**. Since both of these variables are now integers, no type conversion takes place. The next operation is the division between **ch*i** and **f**. The algorithm specifies that if one of the operand is a float, the other will be converted to a float. The result of **ch*i** will be converted to a floating point number then divided by **f**. Finally, the value of the expression **ch*i/f** is a float, but will be converted to a double for storage in the variable **result**.

Instead of relying on the compiler to make the type conversions, you can specify the type conversions by using the following format:

```
(type) value
```

This is called type casting. This causes a temporary change in the variable. **type** is a valid C data type and **value** is the variable or constant. The following code fragment shows how to print the integer portion of a floating point number.

```
float f;
f = 100.2;
printf("%d",(int)f);
```

The number 100 will be printed to the screen after the segment of code is executed. If two 8-bit integers are multiplied, the result will be an 8-bit value. If the resulting value is assigned to a long, the result will still be an 8-bit integer as the arithmetic is performed before the result is assigned to the new variable.

```
int a = 250, b = 10;
long c;
c = a * b;
```

The result will be 196. So if you need a long value as the answer, then at least one value needs to be initially defined as long or typecast.

```
c = (long) a * b;
```

The result will be 2500 because **a** was first typecast to a **long** and therefore a **long** multiply was done.

2.7 variable Storage Class

Every variable and function in C has two attributes – type and storage class. The type has already been discussed as **char**, **int**, etc. There are four storage classes: automatic, external, static and register. These storage classes have the following C names:

```
auto      extern    static    register
```

Auto

Variables declared within a function are auto by default, so

```
{
   char c;
   int a, b, e;
}
```

is the same as

```
{
   auto char c;
   auto int a, b, e;
}
```

When a block of code is entered, the compiler assigns RAM space for the declared variables. The RAM locations are used in that 'local' block of code and can/will be used by other blocks of code.

```
main()
{
   char c = 0;
   int a =1, b = 3, e = 5;
   0007:  CLRF   0E  - register 0Eh assigned to C
   0008:  MOVLW  01  - load w with 1
   0009:  MOVWF  0F  - load register assigned to a with w
   000A:  MOVLW  03  - load w with 3
   000B:  MOVWF  10  - load register assigned to b wit w
   000C:  MOVLW  05  - load w with 5
   000D:  MOVWF  11  - load register assigned to e with w
}
```

Extern

The extern keyword declares a variable or a function and specifies that it has external linkage. That means its name is visible files other than the one in which it is defines. There is no function within the CCS C.

Static

The variable class **`static`** defines globally active variables which are initialized to zero, unless otherwise defined.

```
void test()
{
    char x,y,z;
    static int count = 4;
    printf("count = %d\n",++count);
}
```

The variable **`count`** is initialized once, and thereafter increments every time the function test is called.

Register

The variable class register originates from large system applications where it would be used to reserve high speed memory for frequently used variables. The class is used only to advise the compiler – no function within the CCS C.

Functions

Functions are the basic building blocks of the C language. All statements must be within functions. In this chapter we will discuss how to pass arguments to functions and how to receive an argument from a function.

The topics discussed in this chapter are:

Passing Arguments to Functions
Returning Arguments from Functions
Function Prototypes
Classic and Modern Function Declarations

3.1 Functions

In previous sections, we have seen many instances of functions being called from a main program. For instance:

```
main()
{
    f1();
}

int f1()
{
    return 1;
}
```

In reality, this program should produce an error or, at the very least, a warning. The reason is that the function **f1()** must be declared or defined before it is used, just like variables. If you are using a standard C function, the header file that you included at the top of your program has already informed the compiler about the function. If you are using one or your functions, there are two ways to correct this error. One is to use function prototypes, which are explained in the next section. The other is to reorganize your program like this:

```
int f1()
{
    return 1;
}

main()
{
    f1();
}
```

An error will not be generated because the function **f1()** is defined before it is called in **main()**.

3.2 Function Prototypes

There are two methods used to inform the compiler what type of value a function returns. The general form is:

```
type function_name();
```

For instance, the statement in **sum()** would tell the compiler that the function **sum()** returns an integer. The second way to inform the compiler about the return value of a function is the function prototype. A function prototype not

only gives the return value of the function, but also declares the number and type of arguments that the function accepts. The prototype must match the function declaration exactly.

Prototypes help the programmer to identify bugs in the program by reporting any illegal type conversions between the arguments passed to a function and the function declaration. It also reports if the number of arguments sent to a function is not the same as specified in the function declaration.

The general format for a function prototype is shown here:

```
type function_name(type var1, type var2, type var3);
```

In the above example, the type of each variable can be different. An example of a function prototype is shown in this program. The function calculates the volume defined by length, width and height.

```
int volume(int s1, int s2, int s3);

void main()
{
    int vol;
    vol = volume(5,7,12);
    printf("volume: %d\n",vol);
}

int volume(int s1, int s2, int s3)
{
    return s1*s2*s3;
}
```

Notice that the return uses an expression instead of a constant or variable.

The importance of prototypes may not be apparent with the small programs that we have been doing up to now. However, as the size of programs grows from a few lines to many thousands of lines, the importance of prototypes in debugging errors is evident.

EXERCISE:

1. To show how errors are caught by the compiler, change the above program to send four parameters to the function volume:

```
vol = volume(5,7,12,15)
```

2. Is the following program correct? Why/Why not?

```
double myfunc(void)
```

```
void main()
{
    printf("%f\n",myfunc(10.2));
}

double myfunc(double num)
{
    return num/2.0;
}
```

3.3 Void

One exception is when a function does not have any parameters passed in or out. This function would be declared as such:

```
void nothing (void)
```

An example of this could be:

```
double pi(void)             //defining the function
{                           //with nothing passed in
    return 3.1415926536;    //but with pi returned
}

main()
{
    double pi_val;
    pi_val = pi();          //calling the value of pi
    printf("%d\n",pi_val);
}
```

3.4 Using Function Arguments

A function argument is a value that is passed to the function when the function is called. C allows from zero to several arguments to be passed to functions. The number of arguments that a function can accept is compiler dependent, but the ANSI C standard specifies that a function must be able to accept at least 31 arguments.

When a function is defined, special variables must be declared to receive parameters. These special variables are defined as formal parameters. The parameters are declared between the parenthesis that follow the function's name. For example, the function below calculates and prints the sum of two integers that are sent to the function when it is called.

```
void sum(int a, int b)
{
    printf("%d\n",a+b);
}
```

An example of how the function would be called in a program is:

```
void sum(int a, int b);    //This is a function prototype

main()
{
    sum(1,10);
    sum(15,6);
    sum(100,25);
}
void sum(int a, int b)
{
    printf("%d\n",a+b);
}
```

When **sum()** is called, the compiler will copy the value of each argument into the variables a and **b**. It is important to remember that the values passed to the function **(1,10,15,6,100,25)** are called arguments and the variables **a** and **b** are the formal parameters.

Functions can pass arguments in two ways. The first way is called "call by value". This method copies the value of an argument into the formal parameter of the function. Any changes made to the formal parameter do not affect the original value of the calling routine. The second method is called "call by reference". In this method, the address of the argument is copied into the formal parameter of the function. Inside this function, the formal parameter is used to access the actual variable in the calling routine. This means that changes can be made to the variable by using the formal parameter. We will discuss this further in the chapter on pointers. For now, we will only use the call by value method when we pass arguments to a function.

EXERCISE:

1. Write a function that takes an integer argument and prints the value to the screen.
2. What is wrong with this program?

```
print_it(int num)
{
    printf("%d\n",num);
}


main()
{
    print_it(156.7);
}
```

3.5 Using Functions to Return Values

Any function in C can return a value to the calling routine. Typically, the function is put on the right side of an equals (=) sign. The return value does not necessarily need to be used in an assignment statement, but could be used in a **printf()** statement. The general format for telling the compiler that a function returns a value is:

```
type function_name(formal parameters)
{
    <statements>
    return value;
}
```

Where **type** specifies the data type of the return value of the function. A function can return any data type except an array. If no data type is specified, then the C compiler assumes that the function is returning an integer (**int**). If your function does not return a value, the ANSI C standard specifies that the function should return **void**. This explicitly tells the compiler that the function does not return a value. This example shows a typical usage for a function that has a return value.

```
#include <math.h>

main()
{
    double result;
    result = sqrt(16.0);
    printf("%f\n",result);
}
```

This program calls the function **sqrt()** which return a floating point number. This number is assigned to the variable **result**. Notice that the header file **math.h** is included because it contains information about s that is used by the compiler.

It is important that you match the data type of the return value of the function to the data type of the variable to which it will be assigned. The same goes for the arguments that you send to a function.

So, how do you return a value from a function? The general form is:

```
return variable_name;
```

Where **variable_name** is a constant, variable or any valid C expression that has the same data type as the return value. The following example shows both

types of functions.

```
func();
sum(int a, int b);

main()
{
    int num;
    num = func();
    printf("%d\n", num);
    num = sum(5,127);
    printf("%d\n",num);
}

func()
{
    return 6;
}

sum(int a, int b)
{
    int result;
    result = a + b;
    return result;
}
```

One important thing to do note, is when a return statement is encountered, the function returns immediately to the calling routine. Any statements after the return will not be executed. The return value of a function is not required to be assigned to a variable or to be used in an expression, however, if it is not the value is lost.

EXERCISE:

1. What a function that accepts an integer number between 1 and 100 and returns the square of the number.

2. What is wrong with this function?

```
main()
{
    double result;
    result = f1();
    printf("%f\n",result);
}

int f1()
{
    return 60;
}
```

3.6 Classic and Modern Function Declarations

The original version of C used a different method of formal parameter declaration. This form, now called the classic form, is shown below:

```
type function_name(var1,var2,...varn)
type var1;
type var2;
   .
type varn;
{
   <statements>
}
```

Notice that the declaration is divided into two parts. Only the names of parameters are included inside the parenthesis. Outside of the parenthesis the data types and formal parameter names are specified.

The modern form, which we have been using in previous examples, is given by:

```
type function_name(type var 1,...type var n)
```

In this type of function declaration, both the data types and formal parameter names are specified between the parenthesis.

The ANSI C standard allows for both types of function declarations. The purpose is to maintain compatibility with older C programs of which there are literally billions of lines of C code. If you see the classic form in a piece of code, don't worry; your C compiler should be able to handle it. Going forward, you should use the modern form when writing code.

EXERCISE:

1. What is a function prototype and what are the benefits of using it?

2. Convert this program using a classical form for the function declarations to the modern form.

```
void main(void)
{
   printf("area = %d\n", area(10,15));
}

area(1,w)
int 1,w
{
   return 1*w;
}
```

3.7 Passing Constant Strings

Because the PICmicro® MCU has limitations on ROM access, constant strings cannot be passed to functions in the ordinary manner.

The CCS C compiler handles this situation in a non-standard manner. If a constant string is passed to a function that allows only a character parameter then the function is called for every character in the string. For example:

```
void lcd_putc(char c)
{
   .....
}

lcd_putc("abcd");
```

Is the same as:

```
lcd_putc("a");
lcd_putc("b");
lcd_putc("c");
lcd_putc("d");
```

C Operators

In C, the expression plays an important role. The main reason is that C defines more operators than most other languages. An expression is a combination of operators and operands. In most cases, C operators follow the rules of algebra and should look familiar.

In this chapter we will discuss many different types of operators including:

Arithmetic
Relational
Logical
Bitwise
Increment and Decrement
Precedence of Operators

4.1 Arithmetic Operators

The C language defines five arithmetic operators for addition, subtraction, multiplication, division and modulus.

```
+   addition
-   subtraction
*   multiplication
/   division
%   modulus
```

The +, -, * and / operators may be used with any data type. The modulus operator, %, can be used only with integers. The modulus operator gives the remainder of an integer division. Therefore, this operator has no meaning when applied to a floating point number.

The – operator can be used two ways, the first being a subtraction operator. The second way is used to reverse the sign of a number. The following example illustrates the two uses of the – sign.

```
a = a - b     ;subtraction
a = -a        ;reversing the sign of a
```

Arithmetic operators can be used with any combination of constants and/or variables. For example, the following expression is a valid C statement.

```
result = count -163;
```

C also gives you some shortcuts when using arithmetic operators. One of the previous examples, **`a = a - b;`**, can also be written a -=b;. This method can be used with the +, -, *, and / operators. The example shows various ways of implementing this method.

`a*=b`	is the same as	`a=a*b`
`a/=b`		`a=a/b`
`a+=b`		`a=a+b`
`a-=b`		`a=a-b`
`a%=b`		`a=a%b`
`a<<=b`		`a=a<<b`
`a>>=b`		`a=a>>b`
`a&=b`		`a=a&b`
`a|=b`		`a=a|b`
`a^=b`		`a=a^b`

Taking the C code and comparing it to the assembled version shows how the arithmetic function is achieved within the PIC.

```
int a,b,c,;
```

```
        a = b + c;
```
becomes
```
        0007:     MOVF      0F,W      ;load b
        0008:     ADDWF     10,W      ;add c to b
        0009:     MOVWF     0E        ;save in a

        a = b - c;
```
becomes
```
        0007:     MOVF      0F,W      ;load b
        0008:     MOVWF     0E        ;save in a
        0009:     MOVF      10,W      ;load c
        000A:     SUBWF     0E,F      ;subtract from a
```

The importance of understanding assembler becomes apparent when dealing with problems – I have found, at times, that looking at the assembler listing (.LST) points to the C error. One simple fault is the use of = or ==.

```
        a = b;
```
becomes
```
        0007:     MOVF      0F,W      ;load b
        0008:     MOVWF     0E        ;save in a
```

while
```
        a==b;
```
becomes
```
        0007:     MOVF      0F,W      ;load b
        0008:     SUBWF     0E,F      ;subtract from a
        0009:     BTFSC     03,2      ;test if zero
        000A:     GOTO      00D       ;yes - so bypass
```

In the first instance, **a** is made the same as **b**, in the second, **a** is tested to check if it is the same as **b**.

EXERCISE:
1. Write a program that finds the remainder of 5/5, 5/4, 5/3, 5/2, and 5/1.
2. Write a program that calculates the number of seconds in a year.

4.2 Relational Operators

The relational operators in C compare two values and return a true of false result based on the comparison. The relational operators are following:

```
        >       greater than
        >=      greater than or equal to
        <       less than
        <=      less than or equal to
        ==      equal to
```

```
!=     not equal to
```

One thing to note about relational operators is that the result of a comparison is always a 0 or 1, even though C defines true as any non-zero value. False is always defined as zero.

The following examples show some expressions with relational operators.

```
var > 15; if var is less than or equal to 15, the result is 0
(false)
var != 15; if var is greater or less than 15, the result is 1
(true)
```

EXERCISE:

1. Rewrite the following expression using a different relational operator.

```
count != 0
```

2. When is this expression true or false? Why?

```
count >= 35
```

4.3 Logical Operators

The logical operators support the basic logical operations AND, OR, and NOT. Again, these operators return either a 0 for false or 1 for true. The logical operators and truth table for these operators is shown here:

		AND	OR	NOT
p	q	p&&q	p||q	!p
0	0	0	0	1
0	1	0	1	1
1	0	0	1	0
1	1	1	1	0

The logical and relational operators are tightly coupled together when evaluating an expression. An example of linking these operators together is:

```
count>max || !(max==57) && var>=0
```

Another part of C that uses the relational and logical operators is the program control statements that we will cover in the next chapter.

EXERCISE:

1. Rewrite the following expressions using any combination of relational and logical operators.

```
count == 0
```

```
resutl <= 5
```

2. Since C does not explicitly provide for an exclusive OR function, write an XOR function based on the following truth table.

```
p       q          XOR
0       0          0
0       1          1
1       0          1
1       1          0
```

4.4 Bitwise Operators

C contains six special operators which perform bit-by-bit operations on numbers. These bitwise operators can be used only on integer and character data types. The result of using any of these operators is a bitwise operation of the operands. The bit-wise operators are:

```
&       bitwise AND
|       bitwise OR
^       bitwise XOR
~       1's complement
>>      right shift
<<      left shift
```

The general format for using the shift operators is:

```
variable << expression
variable >> expression
```

The value of **expression** determines how many places to the left or right the **variable** is shifted. Each left shift causes all bits to shift one bit position to the left, and a zero is inserted on the right side. The bit that is shifted off the end of the **variable** is lost.

The unique thing to note about using left and right shifts is that a left shift is equivalent to multiplying a number by 2 and a right shift is equivalent to dividing a number by 2. Shift operations are almost always faster than the equivalent arithmetic operation due to the way a CPU works.

An example of all the bitwise operators is shown below.

```
    AND                          OR
    00000101      (5)            00000101      (5)
&   00000110      (6)          | 00000110      (6)
    ----------------             ----------------
    00000100      (4)            00000111      (7)
```

```
    XOR                          NOT (ones compliment)
    00000101     (5)         ~   00000101     (5)
^   00000110     (6)             ----------------
    ----------------             11111010     (250)
    00000011     (3)

    LEFT SHIFT                   RIGHT SHIFT
    00000101     (5)         ~   00000101     (5)
    << 2                         >> 2
    ----------------             ----------------
=   00010100     (20)            00000001     (1)
```

NOTE:
Do not shift by more bits than the operand has – undefined result.

```
    a = b | c;
```
becomes
```
    0007:  MOVF   0F,W      ;load b
    0008:  IORWF  10,W      ;inclusive or with c
    0009:  MOVWF  0E        ;save in a
```

```
    a = b & c;
```
becomes
```
    0007:  MOVF   0F,W      ;load b
    0008:  ANDWF  10,W      ;and function with c
    0009:  MOVWF  0E        ;save in a
```

```
    a = b >> 3;
```
becomes
```
    0007:  MOVF   0F,W      ;load b
    0008:  MOVWF  0E        ;save in a
    0009:  RRF    0E,F      ;rotate contents
    000A:  RRF    0E,F      ;right
    000B:  RRF    0E,F      ;three times
    000C:  MOVLW  1F        ;apply mask to contents
    000D:  ANDWF  0E,F      ;of register for a
```

```
    j = ~a;
```
becomes
```
    0007:  MOVF   0F,W      ;load b
    0008:  MOVWF  0E        ;save in j
    0009:  COMF   0E,F      ;compliment j
```

EXERCISE:
1. Write a program that inverts only the MSB of a signed char.
2. Write a program that displays the binary representation of a number with the data type of char.

4.5 Increment and Decrement Operators

How would you increment or decrement a variable by one? Probably one of two statements pops into your mind. Maybe following:

```
a = a+1;      or     a = a-1;
```

Again, the makers of C have come up with a shorthand notation for increment or decrement of a number. The general formats are:

```
a++;          or     ++a;       for increment
a--;          or     --a;       for decrement
```

When the ++ or – sign precedes the variable, the variable is incremented then that value is used in an expression. When the ++ or – follows the variable, the value of the variable is used in the expression then incremented.

```
int j, a = 3;
    0007:  MOVLW  03
    0008:  MOVWF  0F         ;register assigned to a

j = ++a;
    0009:  INCF   0F,F       ;a = 4
    000A:  MOVF   0F,W       ;load a in w
    000B:  MOVWF  0E         ;store w in j

j = a++;
    000C:  MOVF   0F,W       ;load value of a into w
    000D:  INCF   0F,F       ;a = 5
    000E:  MOVWF  0E         ;j = 4
```

NOTE:
Do not use the format

```
a = a++;
```

as the following code will be generated:

```
   MOVF   0E,W       ;value of a loaded into w
   INCF   0E,F       ;value in a incremented
   MOVWF  0E;previous value reloaded overwriting incremented
value
```

The following example illustrates the two uses.

```
void main(void)
{
   int i,j;
```

```
    i = 10;
    j = i++;
    printf("i = %d, j = %d\n",i,j);
    i = 10;
    j = ++i;
    printf("i = %d, j = %d\n",i,j);
}
```

The first **printf()** statement will print an **11** for **i** and a **10** for **j**. The second **printf()** statement will print an **11** for both **i** and **j**.

Mixing it all together

Write	Operation	
sum = a+b++	**sum = a+b**	**b = b+1**
sum = a+b--	**sum = a+b**	**b = b-1**
sum = a+ ++b	**b = b+1**	**sum = a+b**
sum = a+ -b	**b = b-1**	**sum = a+b**

ERERCISE:

1. Rewrite the assignment operations in this program to increment or decrement statements.

```
void main(void)
{
    int a, b;

    a = 1;
    a = a+1;
    b = a;
    b = b-1;
    printf("a=%d, b=%d\n", a,b);
}
```

2. What are the values of **a** and **b** after this segment of code finishes executing?

```
a = 0;
b = 0;
a = ++a + b++;
a++;
b++;
b = -a + ++b;
```

4.6 Precedence of Operators

Precedence refers to the order in which operators are processed by the C compiler. For instance, if the expression **a+b*c** was encountered in your program, which operation would happen first? Addition or multiplication? The C language maintains precedence for all operators. The following shows the precedence from highest to lowest.

Priority	Operator	Example	
1	() ++ --	(a+b)/c	parenthesis
2	sizeof & * + - ~ ! ++ --	a=-b	plus/minus/NOT/compliment increment/decrement/sizeof
3	* / %	a%b	multiple/divide/modulus
4	+ -	a+b	add/subtract
5	<< >>	a=b>>c	shift left or right
6	< > <= >=	a>=b	great/less/equal than
7	== !=	a= =b	
8	&	a=b&c	bitwise AND
9	^	a=b^c	bitwise XOR
10	|	a=b|c	bitwise OR
11	&&	a=b&&c	logical AND
12	||	a=b||c	logical OR
13	= *= /= %= += -= <<= >>= $= ^= |=	a+=b	assignment

Some of these operators we have not yet covered, but don't worry, they will be covered later. The second line is composed entirely of unary operators such as increment and decrement. Parenthesis can be used to set the specific order in which operations are performed.

A couple of examples of using parenthesis to clarity or change the precedence of a statement are:

```
10-2*5 = 0
(10-2)*5 = 40
count*sum+88/val-19%count
(count*sum) + (88/val) - (19%count)
```

EXERCISE:

1. What are the values of **a** and **b** better this segment of code finishes executing?

```
int a=0,b=0;

a = 6 8+3b++;
b += -a*2+3*4;
```

C Program Control Statements

In this chapter you will learn about the statements that C uses to control the flow of execution in your program. You will also learn how relational and logical operators are used with these control statements. We will also cover how to execute loops.

Statements discussed in this chapter include:

if
if-else
for
while
do-while
nesting loops
break
continue
switch
null
return

5.1 if Statement

The **if** statement is a conditional statement. The block of code associated with the **if** statement is executed based upon the outcome of a condition. Again, any not-zero value is true and any zero value is false. The simplest format is:

```
if (expression)          NOTE: no ";" after the expression
   statement;
```

The expression can be any valid C expression. The **if** statement evaluates the expression which was a result of true or false. If the expression is true, the statement is executed. If the expression is false, the program continues without executing the statement. A simple example of an **if** is:

```
if(num>0)
   printf("The number is positive\n");
```

This example shows how relational operators are used with program control statements. The **if** statement can also be used to control the execution of blocks of code. The general format is:

```
if (expression)
{
   .
   statement;
   .
}
```

The braces { and } are used to enclose the block of code. This tells the compiler that if the expression is true, execute the code between the barces. An example of the **if** and a block of code is:

```
if (count <0 )
{
   count =0;
   printf("Count down\n");
}
or  if(TestMode ==1)
{
   ... print parameters to use
}
```

Other operator comparisons used in the **if** statement are:

```
x == y       x equals y
x != y       x is not equal to y
x > y        x great than y
```

```
x < y          x less than y
x <= y         x less than or equal to y
x >= y         x great than or equal to y
x && y         logical AND
x || y         logical OR
```

An example of one such function – converted into assembler is:

```
int j, a =3;
    0007:  MOVLW  03     ;load a with 3
    0008:  MOVWF  0F
if (j == 2)
    0009:  MOVLW  02     ;load w with 2
    000A:  SUBWF  0E,W   ;test for match with j
    000B:  BTFSS  03,2   ;if zero skip
    000C:  GOTO   00F
{
    j = a;
    000D:  MOVF   0F,W   ;if zero then
    000E:  MOVWF  0E     ;load a into j
}
```

EXERCISE:
1. Which of these expressions results in a true value?

```
a. 0
b. 1
c. -1
d. 5*5<25
e. 1==1
```

2. Write a function that tells whether a number is even or odd. The function returns 0 when the number is even and 1 when the number is odd. Call this function with the numbers 1 and 2.

5.2 if-else Statements

What if you have two blocks of code that are executed based on the outcome of an expression? If the expression is true, the first block of code is executed, if the expression is false the second block of code is executed. You would probably use the **`if`** statement combined with an **`else`** statement. The general format for an **`if-else`** statement is:

```
if (expression)
    statement1;
else
    statement2;
```

The format for an **if-else** statement that uses blocks of code (more than one line) is:

```
if (expression)
{
    .
    statement;
    .
}
else
{
    .
    statement;
    .
}
```

Keeping in mind that an **if** or **else** statement can have as many statements as needed. The curly braces can be thrown away when there is only one statement for the **if** or **else**. An example of a single statement **if-else** is:

```
if (num<0)
    printf("Number is negative.\n");
else
    printf("Number is positive.\n");
```

The addition of the **else** statement provides a two-way decision path for you. But what if you wanted to combine many **if** and **else** statements together to make many decisions? What a coincidence, C provides a method by which you can combine **if's** with **else's** to provide many levels of decision. The general format is:

```
if (expression1)
{
    .
    statement(s)
    .
}
else if(expression2)
{
    .
    statement(s)
    .
}
else
{
    .
    statement(s)
    .
}
```

Here we see that many different expressions can be evaluated to pick a block of code to execute. Rather than explain any more about this method, here is a simple example.

```
if(num == 1)
   printf("got 1\n");
else if(num == 2)
   printf("got 2\n");
else if(num == 3)
   printf("got 3\n");
else
   printf("got nothing\n");
```

NOTE:
Within the **if** statement, care must be made to ensure correct use of the single and double comparison (i.e., a single &, = or | has the effect of causing the function to act upon the variable as opposed to the double &&, == or || which acts as a comparison of the variable under test. This is a common mistake and may not be immediately apparent as code will compile but will fail in operation

EXERCISE:
1. Is this fragment of code correct?

```
if (count>20)

   printf("count is greater than 20");
   count- ;
}
```

2. Write a program that prints either cents, 5 cents, 10 cents, 20 cents, 50 cents or a dollar depending on the value of the variable. The only valid values for the variable are 1, 5, 10, 25, 50 and 100

5.3 ? Operator

The ? operator is actually an expression version of the **if else** statement. The format is:

```
(expr1) ? (expr2) : (expr3);
```

Where each of the **expr?** is a valid C statement. First, **expr1** is evaluated. If the result is TRUE (remember that this is any non-zero value), then **expr2** is evaluated. If the result is FALSE (zero), then **expr3** is evaluated. The following is an example of the **?** operator.

```
int i,j;
i = j;
i ? j=0 : j=1;       or     j=i?0:1;
```

Since **i** is 1 or non-zero, the expression **j=0** will be evaluated. Unlike an **if** statement the **?** operator returns a value. For example:

```
i = (i<20) ? i+1 : 10;
```

i will be incremented unless it is 20 or higher, then it is assigned 10.

5.4 for Loop

One of the three loop statements that C provides is the **for** loop. If you have a statement or set of statements that needs to be repeated, a **for** loop easily implements this. The basic format of a **for** loop is similar to that of other languages, such as BASIC or Pascal. The most common form of a **for** loop is:

```
for( initialization ; conditional_test ; increment )
```

The **initialization** section is used to give an initial value to the loop counter variable. Note that this counter variable must be declared before the **for** loop can use it. This section of the **for** loop is executed only once. The **conditional_test** is evaluated prior to each execution of the loop. Normally this section tests the loop counter variable for a true or false condition. If the **conditional_test** is true the loop is executed. If the **conditional_test** is false the loop exits and the program proceeds. The **increment** section of the **for** loop normally increments the loop counter variable.

Here is an example of a **for** loop:

```
void main(void)
{
    int i;
    for(i=0; i<10; i++)
       printf("%d ",i);
    printf("done");
}
```

This program will print the numbers 0 – 9 on the screen. The program works like this: First the loop counter variable, **i**, is set to zero; next the expression **i<10** is evaluated. If this statement is true the **printf("%d ",i);** statement is executed. Each time after the **printf("%d ",i);** is executed, the loop counter variable is incremented. This whole process continues until the expression **i<10** becomes false. At this point, the **for** loop is exited and the **printf("done");** statement is executed.

As previous stated, the conditional test is performed at the start of each iteration of the loop. Therefore, if the test is false to start off with, the **for** loop will never be executed. You are not restricted just to incrementing the counter variable. Here are some variations on the **for** loop:

```
for (num=100; num>0; num=num-1)
for (count=0; count<50; count+=5)
for (count=1; count<10 && error==false; count++)
```

Convert an example in to assembler to see what happens:

```
int h,a;
for (h=0;h!=10;h++)
    0007:  CLRF   0E     ;clear h
    0008:  MOVLW  0A     ;load 10
    0009:  SUBWF  0E,W   ;subtract from h
    000A:  BTFSC  03,2   ;and test for zero
    000B:  GOTO   00F    ;if i=10, exit loop
a++;
    000C:  INCF   0F,F   ;increment a
    000D:  INCF   0E,F   ;increment h
    000E:  GOTO   008    ;loop again
```

EXERCISE:
1. What do the following **for()** statements do?

```
for(i=1; ;i++)
for( ; ; )
for(num=1; num; num++)
```

2. Write a program that displays all the factors of a number.

5.5 while Loop

Another loop in C is the **while** loop. While an expression is true, the **while** loop repeats a statement or block of code. Hence, the name **while**. Here is the general format:

```
while (expression)
    statement;
```

or

```
while (expression)
{
    statement;
}
```

The **expression** is any valid C expression. The value of **expression** is checked

prior to each iteration of the statement or block of code. This means that if **expression** is false the statement or block of code does not get executed. Here is an example of a **while** loop:

```
#include <16C74.H>
#use RS232 (Baud=9600, xmit-pin_c6, RCV=pin_c7)
void main(void)
{
    char ch;
    printf("Give me a q\n");
    ch=getch();
    while(ch!='q')
        ch=getch();
    printf("Got a q!\n");
}
```

You will notice that the first statement gets a character from the keyboard. Then the expression is evaluated. As long as the value of **ch** is not a **q**, the program will continue to get another character from the keyboard. Once a **q** is received, the **printf** is executed and the program ends.

EXERCISE:

1. What do the following **while** statements do?

```
a. while(i<10)
    {
        printf("%d ",i);
        i++;
    }
b. while(1)
        printf("%d ",i++);
```

2. Write a program that gets characters from the keyboard using the statement **ch=getch();** and prints them to the screen. When a carriage return is encountered, exit the program.

5.6 do-while Loop

The final loop in C is the **do** loop. Here we combine the **do** and **while** as such:

```
do
{
    statements
}
while(expression)
```

In this case the statements are always executed before **expression** is evaluated. The **expression** may be any valid C expression. An example of a

do-while loop is shown:

```
#include <16C74.H>
#use RS232 (Baud=9600, xmit-pin_c6, RCV=pin_c7)

void main(void)
{
   char ch;
   do
   {
      ch = getch();
   }
   while(ch != 'q');
   printf("Got a q!\n");
}
```

This program is equivalent to the example we gave in Section 5.5

EXERCISE:

1. Rewrite both a and b of Exercise 1 in Section 5.5 using a **do-while** loop:
2. Rewrite Exercise 2 in Section 5.5 using a **do-while** loop.

5.7 Nesting Program Control Statements

When the body of a loop contains another loop, the second loop is said to be nested inside the first loop. Any of C's loops or other control statements can be nested inside each other. The ANSI C standard specifies that compilers must have at least 15 levels of nesting.
An example of a nested **for** loop is shown here:

```
i = 0;
while(i < 10)
{
   for(j=0;j<10;j++)
      printf("%d ",i*10+j);
   i++;
}
```

This routine will print the numbers 00 – 99 on the screen.

EXERCISE:

1. Write a program that gets a character from the keyboard (**ch=getch();**). Each time a character is read, use the ASCII value to print an equal number of periods to the screen. For example, if the letter 'D' is entered (ASCII value of 68), your program would print 68 periods to the screen. When a 'Q' is entered, the program ends.

5.8 break Statement

The **break** statement allows you to exit any loop from any point within the body. The **break** statement bypasses normal termination from an expression. When a **break** statement is encountered in a loop, the program jumps to the next statement after the loop. For example:

```
void main(void)
{
    int i;
    for(i=0;i<50;i++)
    {
        printf("%d ",i);
        if(i==15)
            break;
    }
}
```

This program will print the number 0 – 15 on the screen. The **break** statement works with all C loops.

EXERCISE:

1. What does this loop do?

```
for(i=0;1;i++)
{
    printf("Microchip® is great!");
    if(getch()=='q')
    break;
}
```

2. Write three programs, each using one of C's loops, that count forever but exit when a key is hit. You can use the function **kbhit()** to detect when a key is pressed. **kbhit()** returns 1 when a key is pressed and a 0 otherwise. **kbhit()** requires the header file conio.h

5.9 continue Statement

Let's assume that when a certain condition occurs in your loop, you want to skip to the end of the loop without exiting the loop. C has provided you with the **continue** statement. When the program encounters this statement, it will skip all statements between the **continue** and the test condition of the loop. For example,

```
#include <16C74.H>
void main(void)
{
    int i;
    for(i=0;i<100;i++)
    {
```

```
            continue;
            printf("%d ",i);
        }
    }
```

This loop will never execute the **printf()** statement. Each time the **continue** is reached, the program skips the **printf()** and evaluates the expression i <100 after increasing **i**.
A **continue** will cause the program to go directly to the test condition for **while** and **do-while** loops, a **continue** will cause the increment part of the loop to be executed and then the conditional test is evaluated.

5.10 switch Statement

The **if** statement is good for selecting between a couple of alternatives, but becomes very cumbersome when many alternatives exist. Again C comes through by providing you with a **switch** statement. A **switch** statement is equivalent to multiple **if-else** statements. The general form for a **switch** statement is:

```
switch (variable)
{
    case constant1:
        statement(s);
        break;
    case constant2:
        statement(s);
        break;
    case constantN:
        statement(s);
        break;
    default:
        statement(s);
}
```

The variable is successively tested against a list of integer or character constants. When a match is found, the body of statements associated with that constant is executed until a **break** is encountered. If no match is found, the statements associated with **default** are executed. The **default** is optional. An example of a **switch** is:

```
main()
{
    char ch;
    for(;;)
    {
        ch = getch();
        if(ch=='x')
```

```
            return 0;
        switch(ch)
        {
            case '0':
                printf("Sunday\n");
                break;
            case '1':
                printf("Monday\n");
                break;
            case '2':
                printf("Tuesday\n");
                break;
            case '3':
                printf("Wednesday\n");
                break;
            case '4':
                printf("Thursday\n");
                break;
            case '5':
                printf("Friday\n");
                break;
            case '6':
                printf("Saturday\n");
                break;
            default:
                printf("Invalid entry\n");
        }
    }
}
```

This example will read a number between 1 and 7. If the number is outside of this range, the message **`Invalid entry`** will be printed. Values within the range will be converted into the day of the week.

Another example used to set the number of characters per line on a LCD display is as follows. The DIP switch and the characters per line settings read, then separated from the other bits and used to return the appropriate value to the calling routine.

```
byte cp1_sw_get()       //characters per line
{
    byte cp1;
    cp1=portd & 0b01110000; //mask unwanted bits
    switch(cp1)          //now act on value decoded
    {
        case 0x00:    cp1 = 8; break;
        case 0x10:    cp1 = 16; break;
        case 0x20:    cp1 = 20; break;
        case 0x30:    cp1 = 28; break;
        default:  cp1 = 40; break;
```

```
    }
    return(cp1);     //send back value to calling routine
}
```

The ANSI Standard states that a C compiler must support at least 257 **case** statements. No two **case** statements in the same **switches** can have the same values. Also **switches** can be nested, as long as the inner and outer **switches** do not have any conflicts with values. An ANSI compiler must provide at least 15 levels of nesting for switch statements. Here is an example of nested **switches**.

```
switch (a)
{
    case 1:
    switch (b)
    {
        case 0:
            printf("b is false");
            break;
        case 1:
            printf("b is true");
            break;
    }
    break;
    case 2:
        .
        .
```

The **break** statement within the **switch** statement is also optional. This means that two **case** statements can share the same portion of code. An example is provided to illustrate this.

```
void main(void)
{
    int a=6,b=3;
    char ch;
    printf("A = Addition\n");
    printf("S = Subtraction\n");
    printf("M = Multiplication\n");
    printf("D = Division\n");
    printf("Enter Choice:\n");
    ch=getch();

    switch (ch)
    {
        case 'S':
            b=-b;
        case 'A':
            printf("\t\t%d",a+b);
```

```
            break;
        case 'M':
            printf("\t\t%d",a*b);
            break;
        case 'D':
            printf("\t\t%d",a/b);
            break;
        default:
            printf("\t\tSay what?");
    }
}
```

EXERCISE:

1. What is wrong with this segment of code?

```
float f;
switch(f)
{
    case 10.05:
        .
        .
```

2. Use a **switch** statement to print out the value of a coin. The value of the coin is held in the variable coin. The phrases to describe coins are: penny, nickel, dime, quarter, and dollar.
3. What are the advantages of using a **switch** statement over many **if-else** statements?

5.11 null Statement (;)

The null statement is a statement containing only a semicolon (;). It may appear wherever a statement is expected. Nothing happens when the null statement is executed – unlike the NOP in assembler, which introduces a one cycle delay.

Statements such as **do**, **for**, **if** and **while** require that an executable statement appears as the statement body. The null statement satisfies the syntax in those cases.

```
for (i=0;i<10;i++)
    ;
```

In this example, the loop expression of the **for line[i++]=0** initializes the first 10 elements of line to 0. The statement body is a null, since no additional commands are required.

5.12 return Statement

The **return** statement terminates the execution of a function and returns control to the call routine. A value can be returned to the calling function if required but if one is omitted, the returned value is then undefined. If no return is included in the called function, control is still passed back to the calling function after execution of the last line of code. If a returned value is not required, declare the function to have a **void** return type.

```
GetValue(c)
int c;
{
    c++;
    return c;
}

void GetNothing(c)
int c;
{
    c++;
    return;
}

main()
{
    int x;
    x = GetValue();
    GetNothing();
}
```

Array and Strings

In this chapter we will discuss arrays and strings. An array is simply a list of related variables of the same data type.

A string is defined as a null terminated character array, and is also known as the most common one-dimensional array.

Topics that will be discussed:

Arrays
Strings
One-dimensional Arrays
Multidimensional Arrays
Initialization

6.1 One-Dimensional Arrays

An array is a list of variables that are all of the same type and can be referenced through the same name. An individual variable in the array is called an array element. This is a simple way to handle groups of related data.

The general form for declaring one-dimensional arrays is:

```
type var_name [size];
```

Where **type** is a valid C data type, **var_name** is the name of the array, and **size** specifies how many elements are in the array. For instance, if we want an array of 50 elements we would use this statement.

```
int height[50];
```

When an array is declared, C defines the first element to be at an index of 0. If the array has 50 elements, the last element is at an index of 49. Using the above example, say I want to index the 25th element of the array **height** and assign a value of 60. The following example shows how to do this.

```
height[24] = 60;
```

C store one-dimensional arrays in contiguous memory locations. The first element is at the lowest address. If the following segment of code is executed...

```
int num[10];
int i;
for(i=0;i<10;i++)
    0007:  CLRF   18     ;clear i
    0008:  MOVLW  0A
    0009:  SUBWF  18,W   ;now test if < 10
    000A:  BTFSC  03,0
    000B:  GOTO   013    ;if so then stop routine
num[i] = i;
    000C:  MOVLW  0E     ;load start of num area
    000D:  ADDWF  18,W
    000E:  MOVWF  04
    000F:  MOVF   18,W
    0010:  MOVWF  00
    0011:  INCF   18,F
    0012:  GOTO   008
```

array **i** will look like this in memory.

```
element   1   2   3   4   5   6   7   8   9   10
          0   1   2   3   4   5   6   7   8   9
```

Any array element can be used anywhere you would use a variable or constant. Here is another example program. It simply assigns the square of the index to the array element, then print out all elements.

```
#include <16c74.h>
void main(void)
{
    int num[10];
    int i;
    for(i=0;i<10;i++)
        num[i] = i * i;
    for(i=0;i<10;i++)
        printf("%d ",num[i]);
}
```

What happens if you have an array with ten elements and you accidentally write to the eleventh element? C has no bounds checking for array indexes. Therefore, you may read or write to an element not declared in the array. However, this will generally have disastrous results. Often this will cause the program to crash and sometimes even the computer to crash as well.
C does not allow you to assign the value of one array to another simply by using an assignment like:

```
int a[10],b[10];
.
.
a=b;
```

The above example is incorrect. If you want to copy the contents of one array into another, you must copy each individual element from the first array into the second array. The following example shows how to copy the array **`a[]`** into **`b[]`** assuming that each array has 20 elements.

```
for(i=0;i<20;i++)
    b[i] = a[i];
```

EXERCISE:

1. What is wrong with the following segment of code?

```
int i;
char count[10];
for(i=0;i<100;i++)
    count[i]=getch();
```

2. Write a program that first reads 10 characters from the keyboard using **`getch()`**. The program will report if any of these characters match.

6.2 Strings

The most common one-dimensional array is the string. C does not have a built in string data type. Instead, it supports strings using one-dimensional arrays of characters. A string is defined as a 0. If every string must be terminated by a null, then when what string is declared you must add an extra element. This extra element will hold the null. All string constants are automatically null terminated by the C compiler.
Since we are using strings. How can you input a string into your program using the keyboard? The function **`gets(str)`** will read characters from the keyboard until a carriage return is encountered. The string of characters that was read will be stored in the declared array **`str`**. You must make sure that the length of **`str`** is greater than or equal to the number of characters read from the keyboard and the null **`(null = \0)`**.

Let's illustrate how to use the function **`gets()`** with an example.

```
void main(void)
{
    char star[80];
    int i;
    printf("Enter a string (<80 chars):\n");
    gets(str);
    for(i=0;str[i];i++)
       printf("%c",str[i]);
    printf("\n%s",str);
}
```

Here we see that the string can be printed in two ways: as an array of characters using the **`%c`** or as a string using the **`%s`**.

EXERCISE:

1. What is wrong with this program? The function **`strcpy()`** copies the second argument into the first argument.

```
#include <string.h>
void main(void)
{
    char str[10];
    strcpy(str, "Motoroloa who?");
    printf(str);
}
```

2. Write a program that reads a string of characters from the screen and prints them in reverse order on the screen.

6.3 Multidimensional Arrays

C is not limited to one-dimensional arrays. You can create two or more dimensions. For example, to create an integer array called **number** with 5x5 elements, you would use:

```
int number[5][5];   ;uses 25 ram location
```

Additional dimensions can be added simply by attaching another set of brackets. For simplicity, we will discuss only two-dimensional arrays. A two-dimensional array is best represented by a row, column format. Therefore, two-dimensional arrays are accessed a rot at a time, from left to right. The following figure shows a graphical representation of a 5x5 array.
Two-dimensional arrays are used just like one-dimensional arrays. For example, the following program loads a 5x4 array with the product of the indices, then displays the contents of the array in row/column format.

```
void main(void)
{
    int array[5][4];
    int i,j;

    for(i=0;i<5;i++)
        for(j=0;j<4;j++)
            array[i][3]=i*j;

    for(i=0;i<5;i++)
    {
        for(j=0;j<4;j++)
            printf("%d ",array[i][j]);
        printf("\n");
    }
}
```

The output of this program should be look like this:

```
0       0       0       0
0       1       2       3
0       2       4       6
0       3       6       9
0       4       8       12
```

As you can see, when using the multidimensional arrays the number of variables needed to access each individual element increases. Due to the PICmicro® MCU's memory map, arrays of 100 or 10x10 are not possible. However, two of 50 arrays would fit.

EXERCISE:

1. Write a program that declares a 3x3x3 array and loads it with the numbers 1 to 27. Print the array to the screen.

2. Using the program from Exercise 1, print out the sum of each row and column.

6.4 Initializing Arrays

So far you have seen only individual array elements having values assigned. C provides a method in which you can assign an initial value to an array just like you would for a variable. The general form for one-dimensional arrays is shown here:

```
type array_name[size] = {value_list};
```

The **value_list** is a comma separated list of constants that are compatible with the type of array. The first constant will be placed in the first element, the second constant in the second element and so on. The following example shows a 5-element integer array initialization.

```
int i[5] = {1,2,3,4,5};
```

The element **i[0]** will have a value of 1 and the element **i[4]** will have a value of 5.
A string (character array) can be initialized in two ways. First, you may make a list of each individual character as such:

```
char str[3] ('a', 'b', 'c');
```

The second method is to use a quoted string, as shown here

```
char name [5] = "John";
```

You may have noticed that no curly braces enclosed the string, They are not used in this type of initialization because strings in C must end with a null. The compiler automatically appends a null at the end of **"John"**.

Multidimensional arrays are initialized in the same way as one-dimensional arrays. It is probably easier to simulate a row/column format when using two-dimensional arrays. The following example shows a 3x3 array initialization.

```
int num[3][3]={  1,2,3,
                 4,5,6,
                 7,8,9};
```

EXERCISE:
1. Is this declaration correct?

```
int count[3] = 10,0, 5.6, 15.7;
```

2. Write a program that has a lookup table for the square and the cube of a number. Each row should have the number, the square of the number and the cube of the number. Create a 9x3 array to hold the information for numbers 1-9. Ask the user for a number using the statement **`scanf("%d", &num);`**. Then print out the number and its square and cube.

6.5 Arrays of Strings

Arrays of strings are very common in C. They can be declared and initialized like any other array. The way in which you use the array is somewhat different from other arrays. For instance, what does the following declaration define?

```
char name[10][40];
```

This statement specifies that the array **`name`** contains 10 names, up to 40 characters long (including null). To access a string from this table, specify only the first index. For example, to print the fifth name from this array, use the following statement.

```
printf ("%s",names[4]);
```

The same follows for arrays with greater than two dimensions. For instance, if the array **`animals`** was declared as such:

```
char animals[5][4][80];
```

To access a specific string, you would use the first two dimensions. For example, to access the second string in the third list, specify **`animals[2][1]`**.

EXERCISE:

1. Write a program that create a string table containing the words for the numbers 0 through 9. Allow the user to enter a single digit number and then your program will display the respective word. To obtain an index into the table, subtract '0' from the character entered.

6.6 string functions

Strings can be manipulated in a number of ways within a program. One example is copying from a source to a destination via the **`strcpy`** command. this allows a constant string to be inputted into RAM.

```
       #include <string.h>     //the library for string
functions
       char string[10];        //define string array
           .
```

```
        strcpy (string, "Hi There");//setup characters into
string
```

Note that pointers to ROM are not valid in the PICmicro® MCU so you can not pass a constant string to one of these functions. **`strlen("hi")`** is not valid. More examples:

```
        char s1[10], s2[10];

        strcpy(s1,"abc");
        strcpy(s2,"def");
        strcat(s1,s2);
        printf("%u",strlen(s1));   //will print 6
        printf(s1);                //will print abcdef

        if(strcmp(s1,s2)!=0)
           printf("no match");
```

Some other string functions are available such as:

`strcat`	Appends two strings
`strchr`	Looks for first occurrence of a character
`strrchr`	Finds last occurrence of a character
`strcmp`	Compare two strings
`strncmp`	Compare a number of characters in two strings
`stricmp`	Compares two strings ignoring their case (UPPER vs. lower)
`strncpy`	Copies a number of characters from one string to another
`strlen`	Calculates the length of a string
`strlwr`	Replaces upper case with lower case letters
`strpbrk`	Locate the first matching character in two strings
`strstr`	Locate the first occurrence of a character sequence in a string

Ensure the string arrays match the size of the strings being manipulated.

Pointers

The chapter covers one of the most important and most troublesome feature of C, the pointer. A pointer is basically the address of an object.

Some of the topics we will cover in this chapter are:

Pointer Basics
Pointers and Arrays
Passing Pointers to Functions

7.1 Introduction to Pointers

A pointer is a memory location (variable) that holds the address of another memory location. For example, if a pointer variable **a** contains the address of variable **b**, the **a** points to **b**. If **b** is a variable at location 100 in memory, then **a** would contain the value 100.
The general form to declare a pointer variable is:

```
type *var_name;
```

The **type** of a pointer is one of the valid C data types. It specifies the type of variables to which **var_name** can point. You may have noticed that **var_name** is preceded by an asterisk *. This tells the compiler that **var_name** is a pointer variable. For example, the following statement creates a pointer to an integer.

```
int *ptr;
```

The two special operators that are associated with pointers are the ***** and the **&**. The address of a variable can be accessed by preceding the variable with the **&** operator. The ***** operator returns the value stored at the address pointed to by the variable. For example,

```
#include <16c74.h>
void main(void)
{
   int *a,b;     //more than 1 byte may be assigned to a
   b=6;
   a=&b;
   printf("%d",*a);
}
```

NOTE:
By default, the compiler uses one byte for pointers. This means only location 0-255 can be pointed to. For parts with larger memory a two-byte (16-bit) pointer may need to be used. To select 16 bit pointers, use the following directive:

```
#device *=16
```

Be aware more ROM code will be generated since 16-bit arithmetic is less efficient.

The first statement declares two variables: **a**, which is a pointer to an integer and **b**, which is an integer. The next statement assigns the value of 6 to **b**. Then the address of **b** (**&b**) is assigned to the pointer variable **a**. This line can be read as assign **a** the address of **b**. Finally, the value of **b** is displayed to the screen by using the ***** operator with the pointer variable **a**. This line can print the value at the address pointed to by **a**. This process of referencing a value through a pointer is called indirection. A graphical example is shown here.

```
Address:      100    102    104    106
Variable:     i      j      k      ptr
Content:      3      5      -1     102
```

```
int i, j, k;
int *ptr;
```

Initially, **i** is 3 **&i** is 100 (the location of **i**). As **ptr** contains the value 102, ***ptr** is 5 (the content of address 102)

It is also possible to assign a value to a memory location by using a pointer. For instance, let's restructure the previous program in the following manner.

```
#include <16c74.h>

void main(void)
{
    int *a,b;
    a = &b;
    *a=6;
    printf("%d",b);
}
```

In this program, we first assign the address of variable **b** to **a**, then we assign a value to **b** by using **a**. The line ***a=6;** can be read as assign the value 6 to the memory location pointed to by **a**. Obviously, the use of a pointer in the previous two examples is not necessary but it illustrates the usage of pointers.

EXERCISE:

1. Write a program with a **for** loop that counts from 0 to 9 and displays the numbers on the screen. Print the numbers using a pointer.

7.2 Restrictions to Pointers

In general, pointers may be treated like other variables. However, there are a few rules and exceptions that you must understand. In addition to the ***** and **&** operators, there are only four other operators that can be applied to pointer variables: **+, ++, -, --**. Only integer quantities may be added or subtracted from pointer variables.

When a pointer variable is incremented, it points to the next memory location. If we assume that the pointer variable **p** contains the address 100, after the statement, **p++;** , executes, p will have a value of 102 assuming that integers are two bytes long. If **p** had been a **float** pointer, **p** would contain the value 104 after the increment assuming that floating point numbers are four bytes long. The only pointer arithmetic that appears as expected is for the **char** type, because characters are only one byte long.

You can add or subtract any integer value you wish, to or from a pointer. For example, the following statement:

```
int *p;
.
p = p+200;
```

Cause **p** to point to the 200th memory location past the one to which **p** was previously pointing.

It is possible to increment or decrement either the pointer itself or the object to which it points. You must be careful when incrementing or decrementing the object pointed to by a pointer. What do you think the following statement will do if the value of **ptr** is 1 before the statement is executed?

```
*p++;
```

This statement gets the value pointed to by **p**, then increments **p**. To increment the object that is pointed to by a pointer, use the following statement:

```
(*p)++;
```

The parenthesis cause the value that is pointed to by **p** to be incremented. This is due to the precedence of ***** versus **++**.

Pointers may also be used in relational operations. However, they only make sense if the pointers relate to each other, i.e. they both point to the same object.

Pointers cannot be created to ROM. For example, the following is **illegal:**

```
char const name[5] = "JOHN";
    .
ptr=&name[0];
```

This is valid without the **const** puts the data into ROM.

EXERCISE:

1. Declare the following variables and assign the address of the variable to the pointer variable. Print the value of each pointer variable using the **%p**. Then increment each pointer and print out the value of the pointer variable again. What are the sizes of each of the data types on your machine?

```
char *cp,ch;
int *ip,i;
```

```
float *fp,f;
double *dp,d;
```

2. What is wrong with this fragment?

```
int *p,i;
p = &i;
p = p/2;
```

7.3 Pointers and Arrays

In C, pointers and arrays are closely related and are sometimes interchangeable. It is this relationship between the two that makes the power of C even more apparent.

If you use an array name without an index, you are actually using a pointer to the beginning of the array. In the last chapter, we used the function **`gets()`**, in which we passed only the name of the string. What is actually passed to the function, is a pointer to the first element in the string. Important note: when an array is passed to a function, only a pointer to the first element is passed; they cannot be created for use with constant arrays or structures.

Since an array name without an index is a pointer, you can assign that value to another pointer. This would allow you to access the array using pointer arithmetic. For instance,

```
int a[5]={1,2,3,4,5};

void main(void)
{
    int *p,i;
    p=a;
    for(i=0;i<5;i++)
        printf("%d",*(p+i));
}
```

This is a perfectly valid C program. You will notice that in the **`printf()`** statement we use **`*(p+i)`**, where **`i`** is the index of the array. You may be surprised that you can also index a pointer as if it were an array.
The following program is valid.

```
int a[5]={1,2,3,4,5};
void main(void)
{
    int *p,i;
    p=a;
    for(i=0;i<5;i++)
        printf("%d",p[i]);
```

```
}
```

One thing to remember is that a pointer should only be indexed when it points to an array. Since pointers to arrays point only to the first element or base of the string, it is invalid to increment the pointer. Therefore, this statement would be invalid for the previous program, **p++;.**

Mixing pointers and arrays will produce unpredictable results. The following examples show the problem – the second version does not mix pointers and arrays:

```
int *p;
int array[8];
p=array;
    0007:  MOVLW  0F     ;load start of array
    0008:  MOVWF  0E     ;pointer
*p=3;
    0009:  MOVF   0E,W   ;
    000A:  MOVWF  04     ;point at indirect register
    000B:  MOVLW  03     ;load 3
    000C:  MOVWF  00     ;and save at pointed location
array[1]=4;
    000D:  MOVLW  04     ;load 4
    000E:  MOVWF  10     ;into first location of array

int *p;
int array[8];
p=array;
    0007:  MOVLW  0F     ;load start of array
    0008:  MOVWF  0E     ;pointer
p[1]=3;
    0009:  MOVLW  01     ;load array position
    000A:  ADDWF  0E,W   ;add to array start position
    000B:  MOVWF  04     ;load into array pointer
    000C:  MOVLW  03     ;load in 3
    000D:  MOVWF  00     ;save in location pointed to
                            *(array+1) = 4;
    000E:  MOVLW  10     ;load array position
    000F:  MOVWF  04     ;point to it
    0010:  MOVLW  04     ;load 4
    0011:  MOVWF  00     ;save in pointed to location
```

EXERCISE:

1. Is this segment of code correct?

```
int count[10];
    .
count = count+2;
```

2. What value does this segment of code display?

```
int value[5]=(5,10,15,20,25);
int *p;
p = value;
printf("%d",*p+3);
```

7.4 Passing Pointers to Functions

In Section 3, we talked about the two ways that arguments can be passed to functions, "call by value" and "call by reference". The second method passes the address to the function, or in other words a pointer is passed to the function. At this point any changes made to the variable using the pointer actually change the value of the variable from the calling routine.
Pointers may be passed to functions just like any other variables. The following example shows how to pass a string to a function using pointers.

```
#include <16c74.h>
void puts(char *p);
void main(void)
{
   puts("Microchip is great!");
}
void puts(char *p)
{
   while(*p)
   {
      printf("%c",*p);
      p++;
   }
   printf("\n");
}
```

In this example, the pointer **p** points to the first character in the string, the "M". The statement **while(*p)** is checking for the null at the end of the string. Each time through the while loop, the character that is pointed to by **p** is printed. Then **p** is incremented to point to the next character in the string.
Another example of passing a pointer to a function is:

```
void IncBy10(int *n)
{
   *n += 10;
}

void main(void)
{
   int i=0;
```

```
    IncBy10(i);
}
```

The above example may be rewritten to enhance readability using a special kind of pointer parameter called a reference parameter.
Example:

```
void Incby10(int & n)
{
    n += 10;
}

void main(void)
{
    int i=0;
    Incby10(i);
}
```

Both of the above examples show how to return a value from a function via the parameter list.

EXERCISE:

1. Write a program that passes a **`float`** value to a function. Inside the function, the value of –1 is assigned to the function parameter. After the function returns to **`main`**, print the value of the **`float`** variable.
2. Write a program that passes a fl pointer to a function. Inside the function, the value of –1 is assigned to the variable. After the function returns to **`main ()`**, print the value of the **`float`** variable.

Structures and Unions

Structures and Unions represent two of C's most important user defined types. Structures are a group of related variables that can have different data types. Unions are a group of variables that share the same memory space.

In this chapter we will cover:

Structure Basics
Pointers to Structures
Nested Structures
Union Basics
Pointers to Unions

8.1 Introduction to Structures

A structure is a group of related items that can be accessed through a common name. Each of the items within a structure has its own data types, which can be different from each other. C defines structures in the following way:

```
struct tag-name
{
    type element1;
    type element2;
        .
    type elementn;
} variable-list;
```

The keyword **struct** tells the compiler that a structure is about to be defined. Within the structure each **type** is one of the valid data types. These types do not need to be the same. The **tag-name** is the name of the structure. The **variable-list** declares some variables that have a data type of **struct tag-name**. The **variable-list** is optional. Each of the items in the structure is commonly referred to as fields or members. We will refer to them as members.

In general, the information stored in a structure is logically related. For example, you might use a structure to hold the name, address and telephone number of all your customers. The following example is for a card catalog in a library.

```
struct catalog
{
    char author[40];
    char title[40];
    char pub[40];
    unsigned int data;
    unsigned char rev;
} card;
```

In this example, the name of the structure is **catalog**. it is not the name of a variable, only the name of this type of structure.
The variable **card** is declared as a structure of type **catalog**.

To access any member of a structure, you must specify both the name of the variable and the name of the member. These names are separated by a period. For example, to access the revision member of the structure **catalog**, you would use **card.rev='a'** where **card** is the variable name and **rev** is the member. The operator is used to access members of a structure. To print the author member of the structure catalog, you would type:

```
printf("Author is %s\n",card.author);
```

Now that we know how to define, declare and access a structure, what does a structure catalog looks like in memory.

author	40 bytes
title	40 bytes
pub	40 bytes
date	2 bytes
rev	1 byte

If you wanted to get the address of the date member of the **card** structure you would use **&card.date**. If you want to print the name of the publisher, you would use **printf("%s",card.pub)**. What if you wanted to access a specific element in the title, like the 3rd element in the string? Use

```
card.title[2];
```

The first element of title is 0, the second is 1 and, finally the third is 2.
Once you have defined a structure, you can create more structure variables anywhere in the program using:

```
struct tag-name var-list;
```

For instance, if the structure catalog was defined earlier in the program, you can define two more variables like this:

```
struct catalog book,list;
```

C allows you to declare arrays of structures just like any other data type.
This example declares a 50-element array of the structure **catalog**.

```
struct catalog big[50];
```

If you wanted to access an individual structure within the array, you would index the structure variable (i.e. **big[10]**). How would you access the title member of the 10th element of the structure array **big**?

```
big[9].title
```

Structure may also be passed to functions. A function can be return a structure just like any other data type. You can also assign the values of one structure to another simply by using an assignment. The following fragment is perfectly valid

```
struct temp
{
```

```
    int a;
    float b;
    char c;
} var1,var2;
var1.a=37;
var2.b=53.65;
var2 = var1;
```

After this fragment of code executes the structure, variable **var2** will have the same contents as **var1**.
This is an example of initializing a structure.

```
struct example
{
    char who[50];
    char ch;
    int i;
} var1[2]={"Rodger", 'Y',27,"Jack",'N',30};
```

One important thing to note: When you pass a structure to a function, the entire structure is passed by the "call by value" method. Therefore, any modification of the structure in the function will not affect the value of the structure in the calling routine. The number of elements in a structure does not affect the way it is passed to a function.

An example of using this on the PICmicro® to set up an LCD interface would be

```
struct cont_pins
{
    boolean en1;     //enable for all displays
    boolean en2;     //enable for 40x4 line displays
    boolean rs;      //register select
    int data:4;
} cont;
#byte cont = 8;      //control on port d
```

This sets the structure for **cont_pins** and is then handled within the program.
NOTE:
The **:4** notation for data indicates **4 bits** are to be allocated for that item. In this case **D0** will be **en1**, and **D3-6** will be **data**.

```
void LcdSendNibble(byte n)
{
    cont.data=n;          //present data
    delay_cycles(1);      //delay
    cont.en1=1;           //set en1 line high
    delay_us(2);          //delay
    cont.en1=0;           //set en1 line low
```

```
}
```

EXERCISE:

1. Write a program that has a structure with one character and a string of 40 characters. Read a character from the keyboard and save it in the character using **`getch()`**. Read a string and save it in the string using **`gets()`**. Then print the values of the members.
2. What is wrong with this section of code?

```
struct type
{
   int i;
   long l;
   char str[50];
} s;
.
.
i = 10;
```

8.2 Pointers to Structures

Sometimes it is very useful to access a structure through a pointer.
Pointers to structures are declared in the same way that pointers to other data types are declared. For example, the following section of code declares a structure variable **`p`** and a structure pointer variable **`q`** with structure type of temp.

```
struct temp
{
   int i;
   char ch;
} p,q;
```

Using this definition of the temp structure, the statement **`q=&p`** is perfectly valid. Now that **`q`** points to **`p`**, you must use the arrow operator as shown here:

```
q->i=1;
```

This statement would assign a value of 1 to the number **`i`** of the variable **`p`**. Notice that the arrow operator is a minus sign followed by a greater-than sign without any spaces in between.

Since C passes the entire structure to a function, large structures can reduce the program execution speed because of the relatively large data transfer. For this reason, it is easier to pass a pointer to the structure to the function.

One important thing to note is: When accessing a structure member using a structure variable, use the period. When accessing a structure member using a pointer to the structure, you must use the arrow operator.
This example shows how a pointer to a structure is utilized.

```
#include <16c74.h>
#include <string.h>
struct s_type
{
    int i;
    char str[80];
}  s,*p;
void main(void)
{
    p=&s;
    s.i=10;
    p->i=10;
    strcpy(p->str,"I like structures");
    printf("%d %d %s",s.i,p->i,p->str);
}
```

The two lines **`s.i=10`** and **`p->i=10`** are equivalent.

EXERCISE:
1. Is this segment of code correct?

```
struct s_type
{
    int a;
    int b;
} s, *p;
void main(void)
{
    p=&s;
    p.a=100;
}
```

2. Write a program that creates an array of structure three long of the type PICmicro® MCU. You will need to load the structures with a PIC16C5X, PIC16CXX, and a PIC17CXX device. The user will select which structure to print using the keyboard to input a 1, 2, or 3. The format of the structure is:

```
struct PIC
{
    char name[20];
    unsigned char progmem;
    unsigned char datamem;
    char feature[80];
```

```
};
```

8.3 Nesting Structures

So far, you have only seen that members of a structure were one of the C data types. However, the members of structures can also be other structures. This is called nesting structures. For example:

```
#define NUM_OF_PICS 25
struct PIC
{
    char name[40];
    unsigned char progmem;
    unsigned char datamem;
    char feature[80];
};
struct produtcs
{
    struct PIC devices[NUM_OF_PICS];
    char package_type[40];
    float cost;
} list1;
```

The structure product has three elements: an array of **`PIC`** structures called **`devices`**, a string that has the package name, and the cost. These elements can be accessed using the **`list1`** variable.

8.4 Introduction to Unions

A union is defined as a single memory location that is shared by two or more variables. The variables that share the memory location may be of different data types. However, you may only use one variable at a time. A union looks very much like a structure. The general format of the union is:

```
union tag-name
{
    type element1;
    type element2;
        .
        .
    type elementn;
} variable-list;
```

Again, the **tag-name** is the name of the union and the **variable-list** are the variables that have a union type **tag-name**. The difference between unions and structures is that each member of the union shares the same data space. For example, the following union contains three members: an integer, a character array, and a double.

```
union u_type
{
    int i;
    char c[3];
    double d;
} temp;
```

The way that a union appears in memory is shown below. We will use the previous example to illustrate a union. The integer uses two bytes, the character array uses three bytes and the double uses four bytes.

<----------double---------->			
<---------c[2]---------->	<---------c[1]---------->	<---------c[0]---------->	
<----------integer---------->			
element0	element1	element2	element3

Accessing the members of the union is the same as with structures, you use a period. The statement **temp.i** will access the two byte integer member **i** of the union **temp** and **temp.d** will access the four byte double d. If you are accessing the union through a pointer, you would use the arrow operator just like structures.

It is important to note that the size of the union is fixed at complier time to accommodate the largest member of the union. Assuming that doubles are four bytes long, the union **temp** will have a length of four bytes.

A good example of using a union is when an 8-bit microcontroller has an external 12-bit A/D converter connected to a serial port. The microcontroller reads the A/D in two bytes. So we might set up a union that has two **`unsigned chars`** and a **`signed short`** as the members.

```
union sample
{
    unsigned char bytes[2];
    signed short word;
}
```

When you want to read the A/D, you would read two bytes of data from the A/D and store them in the **`bytes`** array. Then, whenever you want to use the 12-bit sample you would use word to access the 12-bit number.

EXERCISE:

1. What are the differences between a structure and an union? What are the similarities?
2. Write a program that has a union with a **`long int`** member and an four byte character array. Your program should print the **`long int`** to the screen a byte at a time.

PIC Specific C

Having understood the basics of C, it is now time to move into the PICmicro® MCU specific settings, functions and operations. Every compiler has its own good and not so good points.

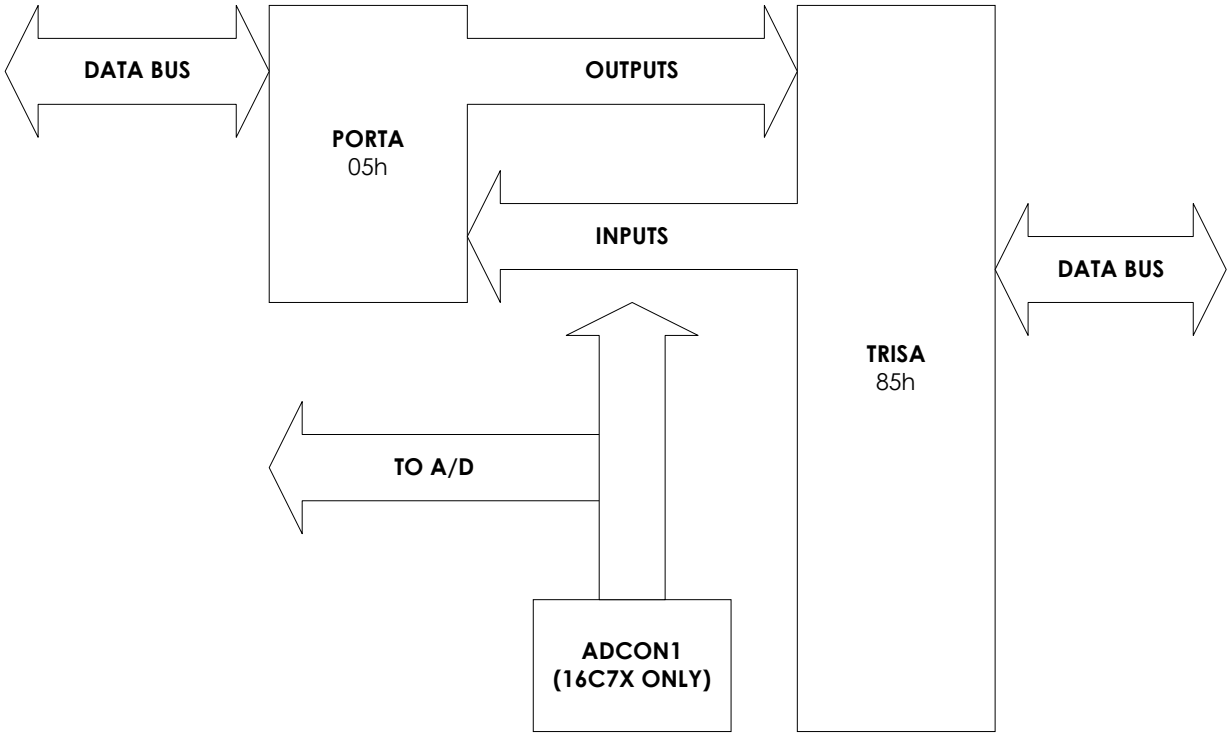
The CCS version has an extensive range of built in functions to save time, and speed up the learning process for newcomers and part time C programmers.

In this chapter we will cover:

Inputs and Outputs
Mixing C and Assembler
A/D Conversion
Data Communications
PWM
LCD Driving
Interrupts
Include Libraries

9.1 Inputs and Outputs

The Input and Output ports on a PICmicro® MCU are made up from two registers – PORT and PORT DIRECTION – and are designated PORTA,B,C,D,E and TRISA,B,C,D,E. Their availability depends upon the PIC being used in the design. An 8pin PIC has a single GPIO register and TRIS register – 6 I/O lines. The 16C74 has PORTS A,B,C,D and E – 33 I/O lines. A block diagram of PORTA is shown below. Ports B,C,D and E are similar but the data sheet needs to be consulted for PIC specifics.



Port A has 5 or 6 lines – depending on the PIC – which can be configured as either inputs or outputs. Configuration of the port direction is via the TRISA register. Inputs are set with a 1 and outputs are set with a 0. The pins have both source and sink capability of typically 25mA per pin.

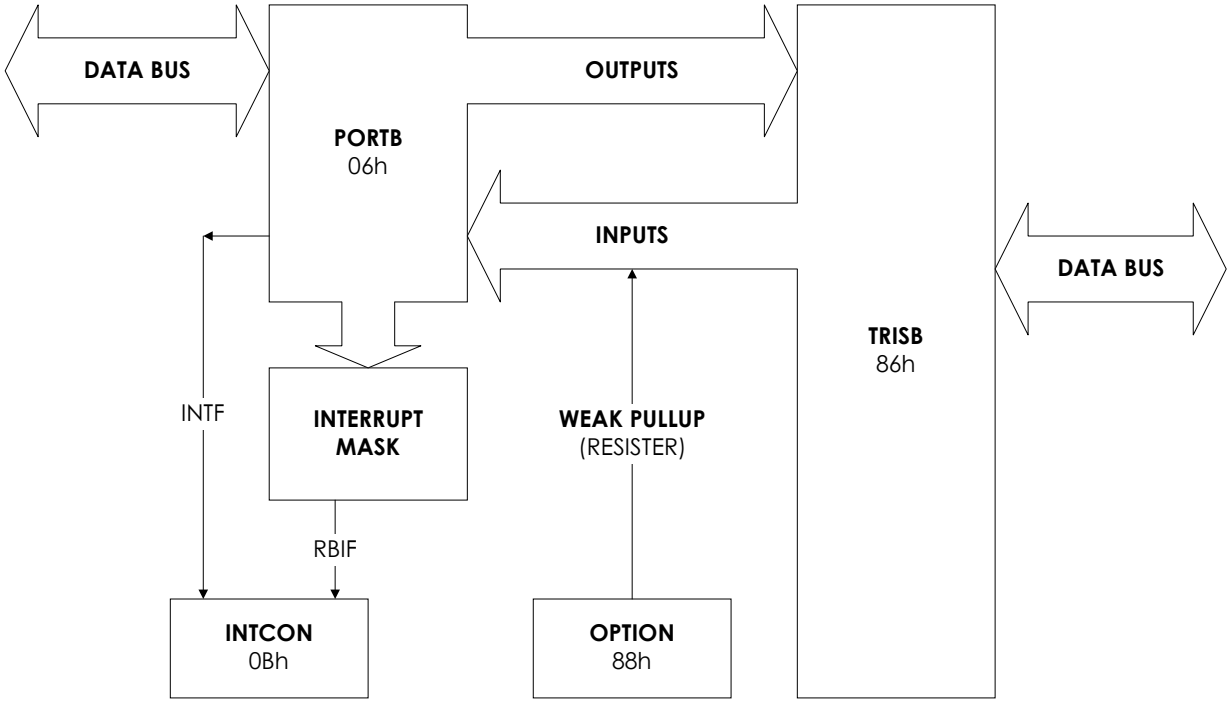
The exception to the I/O lines is the A4 pin which has an open collector output. As a result, the voltage levels on the pin – if tied high with a resistor – is inverted to the bit in the PORTA register (i.e. a logic 1 in porta,4 turns on the transistor and hence pulls the pin low).

An example in assembler could be

```
CLRF      PORTA          ;set outputs low
PAGE1                    ;select register page1
MOVLW     B'00000011'    ;A0,1 as inputs, A2-4 as outputs
MOVWF     PORTA          ;send W to port control register
PAGE0                    ;change back to register page 0
```

Data is sent to the port via a **MOVWF PORTA** and bits can be individually manipulated with either BSF or BCF. Data is read from the port with either **MOVFW PORTA** or bit testing with **BTFSS** or **BTFSC**.

NOTE: On devices with A/D converters, ensure ADCON1 register is also set correctly an I/O default is ANALOG.



Block Diagram of Port B

Port C is similar but does not have the pull-up and interrupt capability of Port B. It does have the additional PICmicro® MCU hardware functions as alternatives to being used as an 8-bit port.

Other Uses for Port C I/O Pins

C0	C1	C2	C3	C4	C5	C6	C7
I/O	I/O	I/O	I/O	I/O	I/O	I/O	I/O
T1OSO	T1OSI	CCP1	SCK	SDI	SDO	TX	RX
T1CKI	CCP2	PWM1	SCL	SDA		CK	DT
	PWM2						

The C compiler can interrupt inputs and outputs in a number of ways – fixed, fast, or standard. In standard mode, the port direction registers are set up prior to each I/O operation. This adds lines to a program and hence slows down the speed, but improves the safety side of the code by ensuring the I/O lines are always set as specified.

Fast I/O enables the user to set the port direction and this remains in place until

re-defined. The compiler does not add lines of code to setup the port direction prior to each I/O operation.

The following example sets Port B as inputs and then reads in the value.

```
set_tris_b(0xff);       //make inputs
b_rate = portb;         //read in port
```

Bit masking is easily achieved by adding the **&** and the pattern to mask after the port name

```
b_rate = portb & 0b00000011;  //mask out unwanted bits
```

The value stored in **b_rate** can then be used to set up a value to return to the calling function. The following is the whole function used to read some dip switches and set up a baud rate for a comms routine.

```
byte bd_sw_get()        //baud rate selection
{
   byte b_rate;
   b_rate = portb & 0b00000011;  //mask out unwanted
bits
   switch(b_rate)
   {
      case 0: set_uart_speed(1200);
              break;
      case 1: set_uart_speed(2400);
              break;
      case 2: set_uart_speed(4800);
              break;
      case 3: set_uart_speed(9600);
              break;
   }
}
```

When setting up portb, it is advisable to set up the port conditions before the port direction registers (TRIS). This prevents the port from outputting an unwanted condition prior to being set. When setting bit patterns in registers or ports, work in binary, as this will make it easier for you writing and others reading the source code. It also saves converting between number bases.

Manipulation of data to and from the I/O ports is made easy with the use of numerous built in functions. On a bit level there are:

```
bit_set(variable, bit);    //used to set a bit
bit_clear(variable, bit);  //used to clear a bit
bit_test(variable, bit);   //used to test a bit
```

The above three can be used on variables and I/O

```
      b = input(pin);          //get the state or value of a pin
      output_bit(pin, value); //set a port pin to a specific
value
      output_float(pin);       //set a pin to input or floating
mode
      output_high(pin);        //set an output to logic 1
      output_low(pin);         //set an output to logic 0
```

On a port wide basic, the following instructions are used:

```
      port_b_pullups(true/false);
```

enables or disables the weak pullup on port b

```
      set_tris_a(value);
```

set the combination of inputs and outputs for a given port – set a 1 for input and 0 for output. This applies to ports b – g.
Port direction registers are configured every time a port is accessed unless the following pre-processor directives are used:

```
      #use fast_io(port)
```

leaves the state of the port the same unless re-configured

```
      #use fixed_io(port_outputs=pin, pin)
```

permanently sets up the data direction register for the port

```
      #use standard_io(port)
```

default for configuring the port every time it's used

9.2 Mixing C and Assembler

There are times when inline assembler code is required in the middle of a C program. The reasons could be for code compactness, timing constraints, or simply because a routine works 'as is'. The following example finds the parity of a value **d** passed to the routine Fiii which is then equated to **a** when the routine is called.

```
      FindParity(type d)
      {
          byte count;
          #asm
              movlw     8
              movwf     count
              clrw
          loop:
              xorwf     d,w
              rrf       d,f
              decfsz    count,f
```

```
        goto      loop
        movwf     _return_
    #endasm
}

main()
{
    byte a,d=7;
    a=FindParity(d);
}
```

When compiled, the program looks like:

```
FindParity(type d)
    {
    byte count;
    #asm
            0005:  MOVLW     8
            0006:  MOVWF     count
            0007:  CLRW
            0008:  XORWF     27,W
            0009:  RRF       27,F
            000A:  DECFSZ    28,F
            000B:  GOTO      008
    #endasm
            000C:  MOVWF     21
            000E:  GOTO      016
    }
main()
    {
            0011:  MOVLW     07
            0012:  MOVWF     26
    byte a,d=7;
    a=FindParity(d);
            0013:  MOVF      26,W
            0014:  MOVWF     27
            0015:  GOTO      005
            0016:  MOVF      21,W
            0017:  MOVWF     25
    }
```

Key to PIC16Cxx Family Instruction Sets

Field Description

b: Bit Address within an 8bit file register (0 - 7)

d: Destination select; d=0 store result in W, d=1 Store in file register f (default)

Assembler recognizes W and f as destinations.

f Register file address (0x00 to 0xFF)

k Literal field, constant data or label; 25h, txt data

W Working register (accumulator)

x Don't care location

i Table pointer control;
i = 0 Do not change, i = 1 increment after instruction execution.

PIC16CXX

Literal and Control Operations

Hex	Mnemonic		Description	Function
3Ekk	ADDLW	K	Add literal to W	k + W >> W
39kk	ANDLW	k	AND literal and W	k .AND. W >> W
2kkk	CALL	k	Call subroutine	PC+1 >> TOS, k >> PC
0064	CLRWDT		Clear watchdog timer	0 >> WDT (and Prescaler, If assigned)
2kkk	GOTO	k	Goto address(k is 9 bits)	k >> PC(9 bits)
38kk	IORLW	k	Incl. OR literal and W	k .OR. W >> W
30kk	MOVLW	k	Move literal to W	k >> W
0009	RETFIE		Return from Interrupt	TOS >> PC, 1 >> GIE
34kk	RETLW	k	Return with literal in W	k >> W, TOS P >> C
0008	RETURN		Return from subroutine	TOS >> PC
0063	SLEEP		Go into Standby Mode	0 >> WDT, stop oscillator
3Ckk	SUBLW	k	Subtract W from literal	k – W >> W
3Akk	XORLW	k	Exclusive OR literal and W	k .XOR. W >> W

Byte Oriented Instructions

Hex	Mnemonic		Description	Function
07Ff	ADDWF	f, d	Add W and f	W + f >> d
05Ff	ANDWF	f, d	AND W and f	W .AND. f >> d
018F	CLRF	f	Clear f	0 >> f
0100	CLRW		Clear W	0 >> W
09Ff	COMF	f, d	Complement f	.NOT. f >> d
03Ff	DECF	f, d	Decrement f	f – 1 >> d
0BFf	DECFSZ	f, d	Decrement f, skip if zero	f – 1 >> d, skip if 0
0AFf	INCF	f, d	Increment f	f + 1 >> d
0FFf	INCFSZ	f, d	Increment f, skip if 0	f + 1 >> d, skip if 0
04Ff	IORWF	f, d	Inclusive OR W and f	W .OR. f >> d
08Ff	MOVF	f, d	Move f	f >> d
008F	MOVWF	f	Move W to f	W >> f
0000	NOP		No operation	
0DFf	RLF	f, d	Rotate left f	
0CFf	RRF	f, d	Rotate right f	
02Ff	SUBWF	f, d	Subtract W from f	f – W >> d
0EFf	SWAPF	f, d	Swap halves f	f(0:3) << f(4:7) >> d
06Ff	XORWF	f, d	Exclusive OR W and f	W .XOR. f >> d

Bit Oriented Instructions

Hex	Mnemonic		Description	Function
10Ff	BCF	f, b	Bit clear f	0 >> f(b)
14Ff	BSF	f, b	Bit set f	1 >> f(b)
18Ff	BTFSC	f, b	Bit test, skip if clear	skip if f(b) = 0
1CFf	BTFSS	f, b	Bit test, skip if set	skip if f(b) = 1

PIC16C5X

Literal and Control Operations

Hex	Mnemonic		Description	Function
Ekk	ANDLW	k	AND literal and W	k .AND. W >> W
9kk	CALL	k	Call subroutine	PC+1 >> TOS, k >> PC
004	CLRWDT		Clear watchdog timer	0 >> WDT (and Prescaler, If assigned)
Akk	GOTO	k	Goto address(k is 9 bits)	k >> PC(9 bits)
Dkk	IORLW	k	Incl. OR literal and W	k .OR. W >> W
Ckk	MOVLW	k	Move literal to W	k >> W
002	OPTION		Load OPTION Register	W >> OPTION Register
8kk	RETLW	k	Return with literal in W	k >> W, TOS P >> C
003	SLEEP		Go into Standby Mode	0 >> WDT, stop oscillator
00f	TRIS	f	Tri-state port f	W >> I/O control register
Fkk	XORLW	k	Exclusive OR literal and W	k .XOR. W >> W

Byte Oriented Instructions

Hex	Mnemonic		Description	Function
1Cf	ADDWF	f, d	Add W and f	W + f >> d
14f	ANDWF	f, d	AND W and f	W .AND. f >> d
06f	CLRF	f	Clear f	0 >> f
040	CLRW		Clear W	0 >> W
24f	COMF	f, d	Complement f	.NOT. f >> d
0Cf	DECF	f, d	Decrement f	f – 1 >> d
2Cf	DECFSZ	f, d	Decrement f, skip if zero	f – 1 >> d, skip if 0
28f	INCF	f, d	Increment f	f + 1 >> d
3Cf	INCFSZ	f, d	Increment f, skip if 0	f + 1 >> d, skip if 0
10f	IORWF	f, d	Inclusive OR W and f	W .OR. f >> d
20f	MOVF	f, d	Move f	f >> d
02f	MOVWF	f	Move W to f	W >> f
000	NOP		No operation	
34f	RLF	f, d	Rotate left f	
30f	RRF	f, d	Rotate right f	
08f	SUBWF	f, d	Subtract W from f	f – W >> d
38f	SWAPF	f, d	Swap halves f	f(0:3) << f(4:7) >> d
18f	XORWF	f, d	Exclusive OR W and f	W .XOR. f >> d

Bit Oriented Instructions

Hex	Mnemonic		Description	Function
4bf	BCF	f, b	Bit clear f	0 >> f(b)
5bf	BSF	f, b	Bit set f	1 >> f(b)
6bf	BTFSC	f, b	Bit test, skip if clear	skip if f(b) = 0
7bf	BTFSS	f, b	Bit test, skip if set	skip if f(b) = 1

PIC16C5X/PIC16CXX

Special Instruction Mnemonics

These instructions are recognized be the Assembler and substituted in the program listing. They are form of shorthand similar to Macros.

Mnemonic		Description	Assembly Code		Flag
ADDCF	f, d	Add Digit Carry to File	BTFSC	Status, Carry	
			INCF	f, d	Z
B	k	Branch	GOTO	k	
BC	k	Branch on Carry	BTFSC	Status, Carry	
			GOTO	k	
BDC	k	Branch on Digit Carry	BTFSC	Status, Digit Carry	
			GOTO	k	
BNC	k	Branch on No Carry	BTFSS	Status, Carry	
			GOTO	k	
BNDC	k	Branch on No Digit Carry	BTFSS	Status, Digit Carry	
			GOTO	k	
BZ	k	Branch on Zero	BTFSC	Status, Zero	
			GOTO	k	
BNZ	k	Branch on No Zero	BTFSS	Status, Zero	
			GOTO	k	
CLRC		Clear Carry	BCF	Status, Carry	
CLRDC		Clear Digit Carry	BCF	Status, Digit Carry	
CLRZ		Clear Zero	BCF	Status, Zero	
MOVWF	k	Move File to W	MOVF	f, W	Z
NEGF	f ,d	Negative File	COMF	f, f	
			INCF	f, d	Z
SETO		Set Carry	BSF	Status, Carry	
SETDC		Set Digit Carry	BSF	Status, Digit Carry	
SETZ		Set Zero	BSF	Status, Zero	
SKPC		Skip on Carry	BTFSS	Status, Carry	
SKPNC		Skip on No Carry	BTFSC	Status, Carry	
SKPDC		Skip on Digit Carry	BTFSS	Status, Digit Carry	
SKPNDC		Skip on No Digit Carry	BTFSC	Status, Digit Carry	
SKPZ		Skip on Zero	BTFSS	Status, Zero	
SKPNZ		Skip on No Zero	BTFSC	Status, Zero	
SUBCF	f, d	Subtract Carry from File	BTFSC	Status, Carry	

			DECF	f, d	Z
SUBDCF	f, d	Sub Digit Carry from File	BTFSC	Status, Digit Carry	
			DECF	f, d	Z
TSTF	f	Test File	MOVF	f, f	Z

9.3 Advanced BIT Manipulation

The CCS C compiler has a number of bit manipulation functions that are commonly needed for PICmicro® MCU programs
bit_set, bit_clear and **bit_test** simply set or clear a bit in a variable or test the state of a single bit. Bits are numbered with the lowest bit (the 1 position) as 0 and the highest bit 7.
For example:

```
c='A';           //c in binary is now 01000001
bit_test(c,5);   //c is now 01100001 or 'a'
if(bit_test(x,0))
   printf("X is odd");
else
   printf("X is even");
```

shift_lest and **shift_right** will shift one bit position through any number of bytes. In addition, it allows you to specify the bit value to put into the vacated bit position. These functions return as their value 0 or 1 representing the bit shifts out. Note, these functions consider the lowest byte in memory the LSB. The second parameter is the number of bytes and the last parameter is the new bit.
Example:

```
int x[3] = {0b10010001, 0b00011100, 0b10000001};
short bb;     //x msb first is: 10000001, 00011100,
10010001
bb = shift_left(x,sizeof(x),0);
                // x msb first is: 00000010, 00111001,
00100010
                //bb is 1
bb = shift_left(x,sizeof(x),1);
                // x msb first is: 00000100, 01110010,
01000101
                //bb is 0
```

Note: The first parameter is a pointer. In this case, since **x** is an array the un-subscripted identifier is a pointer. If a simple variable or structure was used, the & operator must be added. For example:

```
long y;
struct { int a,b,c} z;
shitf_left(&y,2,0);
```

```
shitf_right(&z,3,0);
```

rotate_left and **rotate_right** work like the shift functions above except the bit shifted out of one side gets shifted in the other side. For example:

```
int x[3] = {0b10010001, 0b00011100, 0b10000001};
          //x msb first is: 10000001, 00011100, 10010001
rotate_left(x,sizeof(x));
          //x msb first is: 00000010, 00111001, 00100011
```

The **swap** function swaps the upper 4 bits and lower 4 bits of a byte. For example:

```
int x;
x = 0b10010110
swap(x);  //x is now 01101001
```

9.4 Timers

All PICmicro® 's have an 8-bit timer and some PIC's have two more advanced timers. The capabilities are as follows:

rtcc (timer0) = 8Bit.

May increment on the instruction clock or by an external source.

Applying a pre-scaler may slow increment.

When timer0 overflows from 255 to 0, an interrupt can be generated (not 16C5X series)

timer1 = 16Bit.

May increment on the instruction clock or by an external source.

Applying a pre-scalar may slow increment.

When timer1 overflows from 65535 to 0, an interrupt can be generated.

In capture mode, the timer1 count may be saved in another register when a pin changes. An interrupt may also be generated.

In compare mode, a pin can be changed when the count reaches a preset value, and an interrupt may also be generated.

This timer is used as part of the PWM.

timer2 = 8Bit.

May increment on the instruction clock or by an external source.

Applying a pre-scalar may slow increment.

When timer2 overflows from 255 to 0, an interrupt can be generated.

The interrupt can be slowed by applying a post-scaler, so it requires a certain number of overflows before the interrupt occurs.

This timer is used as part of the PWM.

The following is a simple example using the rtcc to time how long a pulse is high:

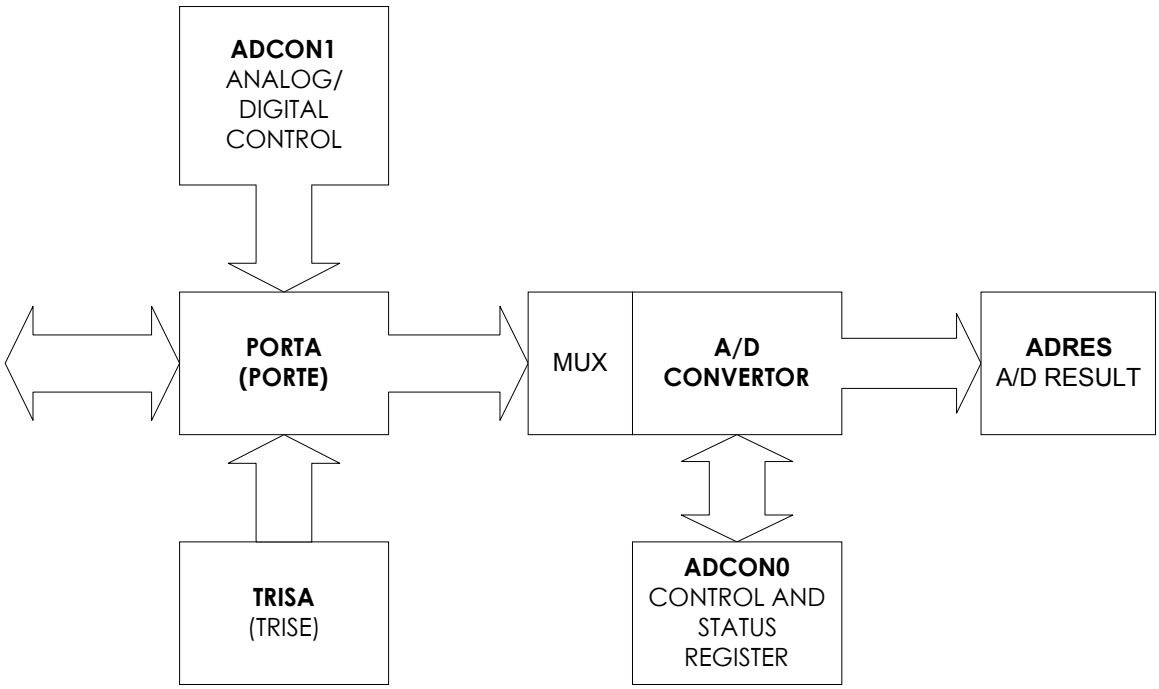
```
#include <16c74.h>
#fuses HS,NOWDT
#use delay(clock=1024000)
#use rs232(baud=9600,xmit=PIN_C6,rcv=PIN_C7)

main() {
   int time;
   setup_counters(rtcc_internal, rtcc_div_256);
          //increments 1024000/4*256 times per second
          //or every millisecond
   while(!input(PIN_B0)); //wait for high
      set_rtcc(0);
   while(!input(PIN_B0)); //wait for low
      time = get_rtcc();
   printf("High time = %u ms.",time);
}
```

The following is an example using the **timer1** capture feature to time how long it takes for pin **C2** to go high after pin **B0** is driven high:

```
#include <16c74.h>
#fuses HS,NOWDT
#use delay(clock=8000000)
#use rs232(baud=9600,xmit=PIN_C6,rcv=PIN_C7)
#bit capture_1 = 0x0c.2    //pir1 register
                          //bit 2 = capture has taken place
main()
{
   long time;
   setup_timer1(t1_internal | t1_div_by_2);
                          //Increments every 1 us
   setup_ccp1(ccp_capture_re);
                          //configure CCP1 to capture rise
   capture_1=0;
```

```
    set_timer1(0);
    output_high(PIN_B0);
    while(!capture_1);
        time = ccp_1;
    printf("Reaction time = %1u us.",time);
}
```



9.5 A/D Conversion

The A/D in the 16C7x and 12C67x devices has a resolution of 8 bits. This means that the voltage being measured can be resolved to one of 255 values. If a 5 volt supply is used, then the measured accuracy is 5/255 = 19.6mV over a 0 to 5 volt range. However, if the reference voltage is reduced to 2.55 volts, the resolution becomes 10mV but the working range falls to 0 to 2.55 volts.

Other Microchip parts have 10, 11, 12 and 16 bits resolution.

NOTE:
The default for ports having both analog and digital capability is ANALOG.

It is important to note which combination of I/O lines can be used for analog and digital. The following tables are extracted from the data sheets.

16C72/3				16C74 only			
A0, A1	**A2**	**A3**	**A5**	**E0**	**E1**	**E2**	**Vref**
A	A	A	A	A	A	A	Vdd
A	A	Vref	A	A	A	A	A3
A	D	A	A	D	D	D	Vref
D	D	Vref	A	D	D	D	A3

A	A	A	D	D	D	D	Vref
A	A	Vref	D	D	D	D	A3
D	D	D	D	D	D	D	---

16C71, 16C710, 16C711

A0, A1	**A2**	**A3**	**Vref**
A	A	A	Vdd
A	A	Vref	A3
A	D	D	Vdd
D	D	D	---

In C, the setup and operation of the A/D is simplified by ready made library routines.

set_adc_channel(0-7)
select the channel for a/d conversion

setup_adc(mode)
sets up the analog to digital converter
The modes are as follows:
adc_off, adc_clock_div_2, adc_clock_div_8, adc_clock_div_32,adc_clock_internal

setup_adc_ports(mix)
will setup the ADC pins to be analog, digital or combination. The allowed combinations for mix vary depending on the chip.
The constants **all_analog** and **no_analog** are valid for all chips. Some other example constants:
ra0_ra1_ra2_ra3_analog/a0_ra1_analog_ra3_ref

read_adc()
will read the digital value fro the analog to digital converter. Calls to **setup_adc** and **set_adc_channel** should be made sometime before this function is called. This function returns an 8-bit value **00h – FFh** on parts with an 8 bits A/D converter. On parts with greater than 8 bits A/D the value returned is always a long with the range **000h – FFFFh**.
The range may be fixed regardless of the part to aid in compatibility across parts by adding on of the following directives:
#device ADC=8
#device ADC=16

Example

```
setup_adc(ALL_ANALOG); //sets porta to all analog inputs
set_adc_channel(1);    //points a/d at channel 1
   delay_ms(5000);     //waits 5 seconds
   value = read_adc(); //reads value
```

```
printf("A/D value = %2x\n\r", value);//prints value
```

9.6 Data Communications/RS232

RS232 communications between PCs, modems etc. form part of an engineer's life. The problem seems to arise when self built products need to be interfaced to the outside world. The permutations of 9 or 25 pins on a D connector and the software controlling communications are endless. A minimum interface can be 3 wires – Ground, Transmit, and Receive – but what to do with the remaining pins? The voltage levels are between ±3 and ±15 volts allowing plenty of leeway for both drivers and receivers. When connecting equipment with RS232 interfaces, it is important to know which is classified as the Data Controlling Equipment (DCE) and which is Data Terminal Equipment (DTE).

Cables/Connectors

9 ways D

Pin	Function	Data direction
1	Carrier Detect	I
2	Receive Data	I
3	Transmit Data	O
4	Data Terminal Ready	O
5	Ground	<>
6	Data Set Ready	I
7	Request To Send	O
8	Clear To Send	I
9	Ring Indicator	I

25 ways D

Pin	Function	Data direction
1	Protective Ground	<>
2	Transmit Data	O
3	Receive Data	I
4	Request To Send	O
5	Clear To Send	I
6	Data Set Ready	I
7	Signal Ground	<>
20	Data Terminal Ready	O
22	Ring Indicator	I

The remaining pins have other functions not normally used for basic interconnection, and are documented in the EIA-232-D or CCTT V24/28 specification.

Common Problems

Result	Possible reasons
Garbled characters	parity, speed, character length, stop bits

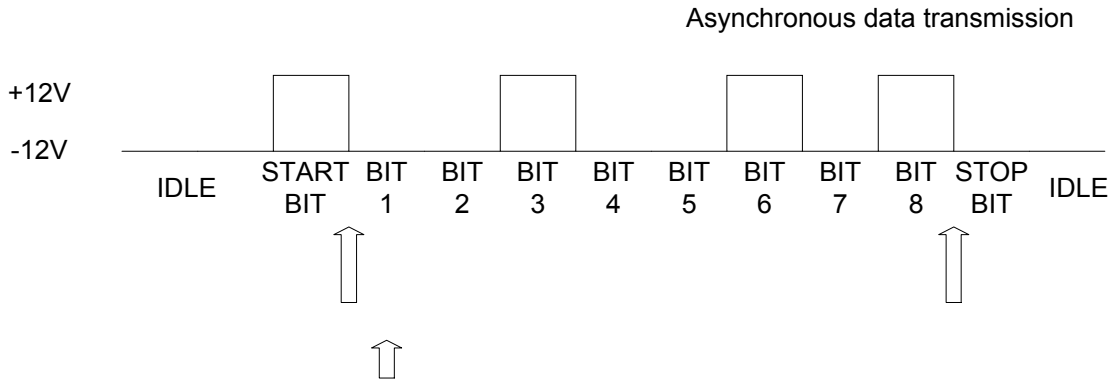
Lost data	flow control
Double space	translation of carriage returns or line feeds
Overwriting	translation of carriage returns or line feeds
No display of characters	duplex operation
Double characters	duplex operation

Data Format

Data sent via an RS232 interface follows a standard format.

Start bits	always 1 bit
Stop bits	1 or 2 bits
Data bits	7 or 8 bits
Parity bits	none if no error detection is required odd or even if error detection is required

DATA FORMAT: 8 DATA BITS, 1 STOP BIT



Parity

Parity checking requires the addition of an extra bit to the data byte. The parity system may be either 'odd' or 'even' and both systems give the same level of error detection.

In an odd parity system, the overall count of '1's in the combined data byte, plus parity bit, is odd. Thus, with an 8 bits data byte of '10101100' the parity bit would be set to '1'.

In an even parity system, the overall count of '1's in the combined data byte, plus parity bit, is even. Thus, with an 8 bits data byte of '10101100' the parity bit would be set to '0'.

If corruption of either data bytes or of the parity bit itself takes place, when the receiver carries out the parity check, the corruption will be recognized. In the event of more than one bit being corrupted, it is possible that the receiver will not recognize the problem, provided that the parity appears correct. So, parity checking is not a cast iron method of checking for transmission errors, but in

practice, it provides a reasonable level of security in most systems. The parity system does not correct errors in itself; it only indicates that an error has occurred and it is up to the system software to react to the error state; in most systems this would result in a request for re-transmission of the data.

The PICmicro® MCU does not have on-chip parity testing or generation, so the function needs to be generated in software. This adds an overhead to the code generated which could have a knock on effect on execution times.

Bit Rate Time Calculation

As BAUD is bits per second, each data bit has a time of 1/(baud rate)
This works out as 1200 baud = 833uS, 2400 baud = 416uS, 9600 baud = 104uS

ASCII Conversion Table

Control

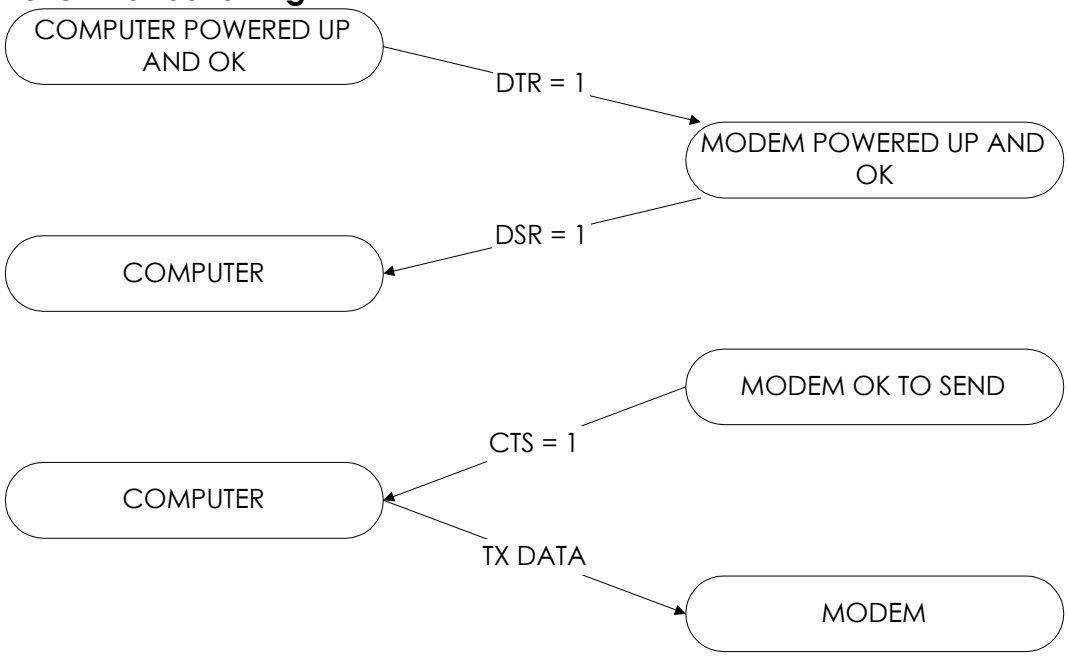
HEX		msb	0	1	2	3	4	5	6	7
	lsb	bits	000	001	010	011	100	101	110	111
	0	0000	NUL	DLE	SP	0	@	P	-	p
^A	1	0001	SOH	DC1	!	1	A	Q	a	q
^B	2	0010	STX	DC2	“	2	B	R	b	r
^C	3	0011	ETX	DC3	#	3	C	S	c	s
^D	4	0100	EOT	DC4	$	4	D	T	d	t
^E	5	0101	ENQ	NAK	%	5	E	U	e	u
^F	6	0110	ACK	SYN	&	6	F	V	f	v
^G	7	0111	BEL	ETB	‘	7	G	W	g	w
^H	8	1000	BS	CAN	(	8	H	X	h	x
^I	9	1001	HT	EM	)	9	I	Y	i	y
^J	A	1010	LF	SUB	*	:	J	Z	j	z
^K	B	1011	VT	ESC	+	;	K	[	k	{
^L	C	1100	FF	FS	,	<	L	\	l	
^M	D	1101	CR	GS	-	-	M	]	m	}
^N	E	1110	SO	RS	.	>	N	^	n	~
^O	F	1111	SI	US	|	?	O	_	o	DEL

Definitions for the ASCII symbols on the previous table are:

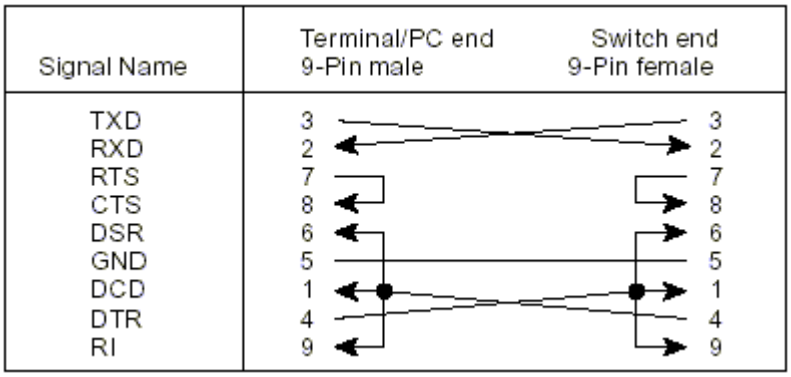
NUL	-	Null	DLE	-	Data Link Escape
SOH	-	Start of Heading	DC	-	Device Control
STX	-	Start of Text	EXT	-	End of Text
EOT	-	End of Transmission	ENQ	-	Enquiry
NAK	-	Negative Acknowledge	ACK	-	Acknowledge
SYN	-	Synchronous Idle	BEL	-	Bell
ETB	-	End Transmission Block	BS	-	Backspace
CAN	-	Cancel	HT	-	Horizontal Tab
EM	-	End of Medium	LF	-	Line Feed
SUB	-	Substitute	VT	-	Vertical Tab
ESC	-	Escape	FF	-	Form Feed
FS	-	File Separator	CR	-	Carriage Return
GS	-	Group Separator	SO	-	Shift Out

RS	-	Record Separator	SI	-	Shift In
US	-	Unit Separator	DEL	-	Delete
SP	-	Space (blank)			
DC1	-	Xon	DC3	-	Xoff

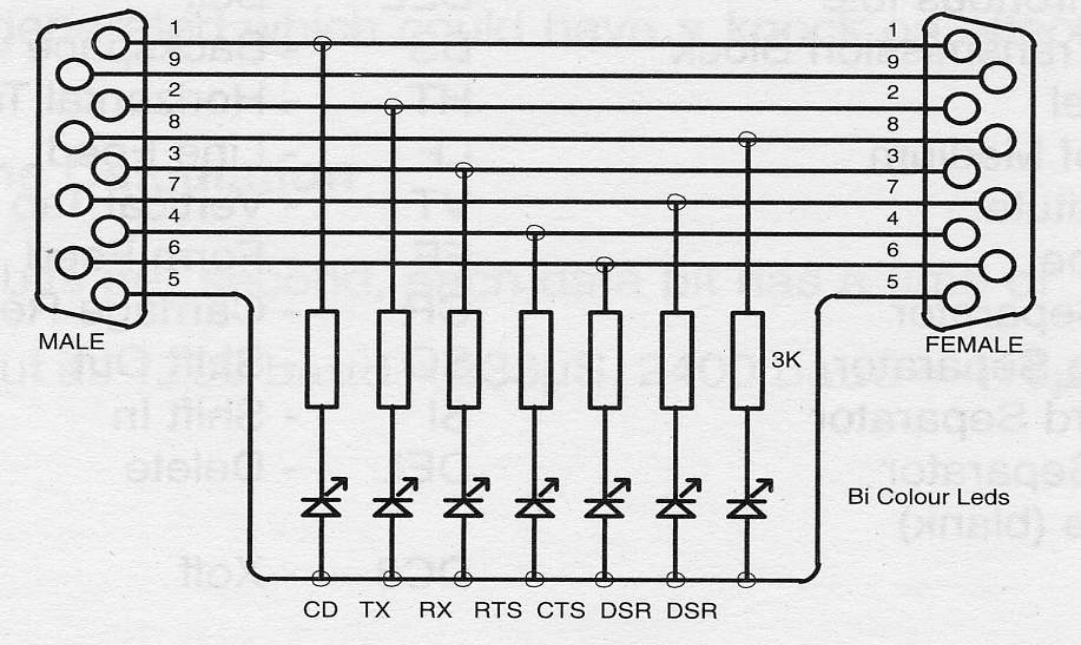
RS232 Handshaking



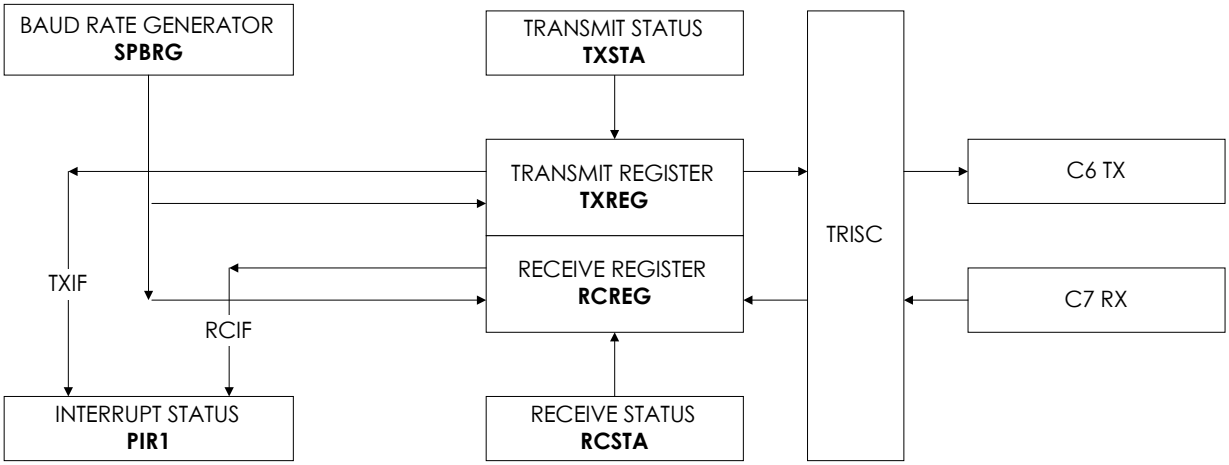
Typical Null Modem Connections



Simple RS232 Tester



USART



The USART operates in one of three modes: Synchronous Master, Synchronous Slave and Asynchronous, the latter being the most common for interfacing peripherals. Besides the obvious interface to PC's and Modems, the USART can interface to A/D, D/A and EEPROM devices.

Data formats acceptable to the USART are: 8 or 9 data bits; none; odd or even parity; created and tested in user software; not a hardware function; and indication of over run or framing errors on the received data. In Asynchronous mode, the USART can handle full duplex communications, but only half duplex in Synchronous mode. There are pre-set functions which speed up application writing:

```
#use fixed_io(c_outputs=pin_C6)   //speeds up port use
#use delay(Clock=4000000)         //clock frequency
#use rs232(baud=4800, xmit=PIN_C6, rcv=PIN_C7)
```

The CCS compiler has the ability to use the on-board PICmicro® MCU's UART if one is present. If the UART is available in hardware, the code generated will use the existing hardware. If, however, the hardware is absent, the resulting code generated will be larger. With the exception of the interrupt on transmit and receive, the code behaves like hardware UART. The software UART has the ability to invert the output data levels, removing the need for an external driver/level shifter in logic level applications. This function is not available in hardware.

This code transparency enables code to be moved from one PICmicro® MCU application to another with minimal effect.

Included in the C compiler are ready-made functions for communications such as:

getc, getch, getchar	waits for and returns a character to be received from the RS232 rev pin
gets(char *string)	reads s string of characters into the variable until a carriage return is received. A 0 terminates the string. The maximum length of characters is determined by the declared array size for the variable.
putc put char	sends a single character to the RS232 xmit pin
puts(s)	sends a string followed by a line feed and carriage return

The function **kbhit()** may be used to determine if a character is ready. This may prevent hanging in **getc()** waiting for a character. The following is an example of a function that waits up to one-half second for a character.

```
char timed_getc()
{
    long timeout;
    timeout_error=FALSE;
    timeout=0;
    while(!kbhit&&(++timeout<50000)) //1/2 second
        delay_us(10);
    if(kbhit)
        return(getc());
    else
    {
        timeout_error=TRUE;
        return(0);
    }
}
```

9.7 I²C Communication

I²C is a popular two-wire communication bus to hardware devices. A single two wire I²C bus has one master and any number of slaves. The master may send or request data to/from any slave. Each slave has a unique address.

The two wires are labeled SCL and SDA. Both require a pull-up resistor (1-10K) to +5V.

Communication begins with a special start condition, followed by the slave address. The LSB of this first byte indicates the direction of data transfer from this point on. Data is transferred and the receiver specifically acknowledges each byte. The receiver can slow down the transfer by holding SCL low while it is busy. After all data is transferred, a stop condition is sent on the bus.

The following is an example C program that will send three bytes to the slave at address 10 and then read one byte back.

```
#include <16C74.h>
#fuses XT, NOWDT
#use delay(clock=4000000)
#use I2C(master, SCL=PIN_B0, SDA=PIN_B1)
main()
{
    int data;
    I2C_START();
    I2C_WRTIE(10);
    I2C_WRTIE(1);
    I2C_WRTIE(2);
    I2C_WRTIE(3);
    I2C_STOP();
    I2C_START();
    I2C_WRTIE(11);
    data=I2C_READ();
    I2C_STOP();
}
```

9.8 SPI Communication

Like I²C, SPI is a two or three wire communication standard to hardware devices. SPI is usually not a bus, since there is one master and one slave.

One wire supplies a clock while the other sends or receives data. If a third wire is used, it may be an enable or a reset. There is no standard beyond this, as each device is different.

The following is C code to send a 10 bits command MSB first to a device. Note: The **`shift_left`** function returns a single bit (the bit that gets shifted out) and this bit is the data value used in the **`output_bit`** function.

```
main()
{
   long cmd;
   cmd=0x3e1;
   for(i=1;i<=6;i++)          //left justify cmd
      shift_left(cmd,3,0);
   output_high(PIN_B0);       //enable device
            //send out 10 data bits each with a clock
pulse
   for(i=0;i<=10;++i)
   {
      output_bit(PIN_B1, shift_left(cmd,2,0));
      output_high(PIN_B2);    //B2 is the clock
      output_low(PIN_B2);
   }
      output_low(PIN_B1);     //disable device
      output_low(PIN_B0);
}
```

The following is C code to read a 8 bits response. Again **shift_left** is used, and the data that is shifted in is bit on the input pin.

```
main()
{
   int data;
   output_high(PIN_B0);       //enable device
                        //send a clock pulse and
                        //read a data bit eight times
   for(i=0;i<=8;++i)
   {
      output_high(PIN_B2);
      output_low(PIN_B2);
      shift_left(&data,1,input(PIN_B1));
   }
      output_low(PIN_B0);     //disable device
}
```

The previous are two great examples of shifting data in and out of the PICmicro® MCU a bit at a time. They can be easily modified to talk to a number of devices. Slower parts may need some delays to be added.

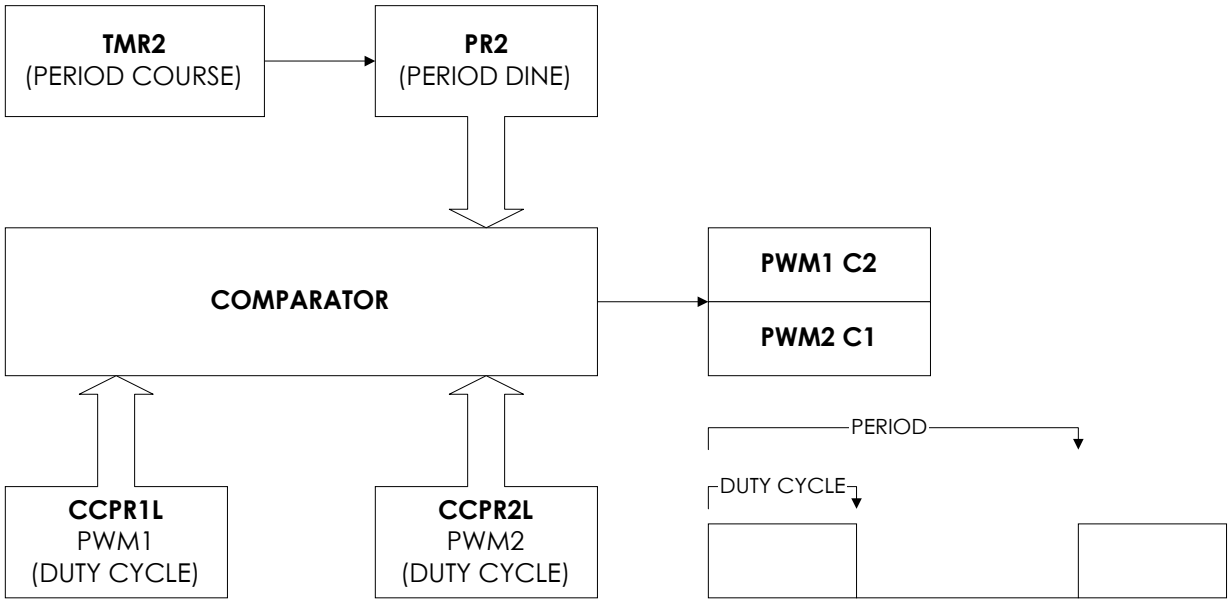
Some PIC's have built in hardware for SPI. The following is an example of using the built in hardware to write and read.

```
main()
{
   int data;
   setup_spi(SPI_MASTER | SPI_H_TO_L | SPI_CLK_DIV_16);
   output_high(PIN_B0);
```

```
        spi_write(3);
        spi_write(0xE1);
        output_low(PIN_B0);
        output_high(PIN_B0);
        data=spi_read(0);
        output_low(PIN_B0);
    }
```

Note: Built in hardware does have restrictions. For example, the above code sent 16 bits not 10. Most SPI devices ignore all bits until the first 1 bit, so this will still work.

9.9 PWM Generation



For PICmicro® MCU's with PWM generation hardware, once the registers are set up, the PWM runs on its own without constant software involvement. Calculation of the PWM values is best achieved with a simple spreadsheet. Example:

PWM setup – frequency = 600Hz M/S ratio = 1:1
Prescale value = ((1/PWM Frequency)/Prescale value * (4/OSC frequency))-1
PWM resolution = (log (OSC freq / PWM freq)) / log 2

So for the above example, a 600Hz PWM with a 4MHz oscillator and /16 prescaler will give 103.2 to load into the PR2 register and a resolution of 12.7 bits

setup_timer_2(mode, period, postscale)
initializes timer 2 where mode is
T2_DISABLED
T2_DIV_BY_1
T2_DIV_BY_4

T2_DIV_BY_16
period is an offset value between 0 and 255 before the timer resets **postscale** is a value between 0 and 16 to determine the times before an interrupt occurs

set_pwm1_duty(value)
this will write the 10 bit value to the PWM module
set_pwm2_duty(value)
If only 8 bits are sent, the 2 lsb's will be ignored. Note, **value** is in the range 0 to **period**
set_ccp1(CCP_PWM), set_ccp2(CCP_PWM)
this function will initialize the CCP in a PWM mode

Example:

```
setup_ccp1(CCP_PWM);    //sets up for pwm
setup_timer_2(T2_DIV_BY_4, 140, 0);
                        //140 as offset, timer 4
set_pwm1_duty(70);
                  //50% duty cycle, i.e. half of 140
```

If oscillator = 4MHz, then frequency will be 1.773KHz with a potential resolution of 11 bits

The following example will generate one of two tones – determined by the value passed to the routine – for a set duration. The frequency is set with the:

```
setup_timer_2(T2_DIV_BY_4, 100, 0);
```

The duty ratio is set with

```
set_pwm1_duty(50);
```

The frequencies for the two tones are 2.475KHz and 996Hz. The duration is set with a simple delay followed by setting the duty cycle to – silence the output even though the PWM is still running.

```
void sound_bell(byte y)
{
   setup_ccp1(CCP_PWM);    //configure CCP1 as a PWM
   if(y==2)
   {
      setup_timer_2(T2_DIV_BY_4, 100, 0);
      set_pwm1_duty(50);  //make this value half of tone
      delay_ms(200);      //0.2 second bell from
terminal
   }
   else
```

```
          {
             setup_timer_2(T2_DIV_BY_4, 250, 0);
             set_pwm1_duty(125); //make this value half of tone
             delay_ms(300);      //0.2 second bell from
terminal
          }
          set_pwm1_duty(0);
       }
```

NOTE:
PICmicro® MCU's without PWM hardware cannot have the function generated by software, unlike the USART function. However, PWM like functions can be simulated.
For example:

```
       while(true)
       {
          output_high(PIN_B0);
          delay_us(500);
          output_low(PIN_B0);
          delay_us(500);
       }
```

This will generate a 1KHz square wave. However, the PIC is dedicated to this operation and cannot do anything else. This can be overcome by toggling the pin in an interrupt routine, set to go off at a fixed rate.

9.10 LCD Display Driving

One of the most common display interfaces to PICmicro® MCU based designs is an LCD display based on the Hitachi controller. There are two modes of operation, 4 and 8 wires, with the option of write/delay or write/check busy when sending data to the display. It is an advantage to have a copy of the current display data sheet, when writing software, showing correct timing and setup codes.

A typical interface circuit is shown below. The PIC interfaces to the display in a 4 bits mode. Register Select (RS) changes between control and data register banks within the display, and the Enable (E) is used to strobe data into the display. In the 4 bits mode, the most significant nibble is sent first.

The initialization code looks like:

```
       byte CONST LCD_INIT_STRING[5] =
                                {0x28, 0x06, 0x0c, 0x01, 0x80};
                                //send to the LCD to start it up
                                //see data sheet
       void lcd_init(byte x)
```

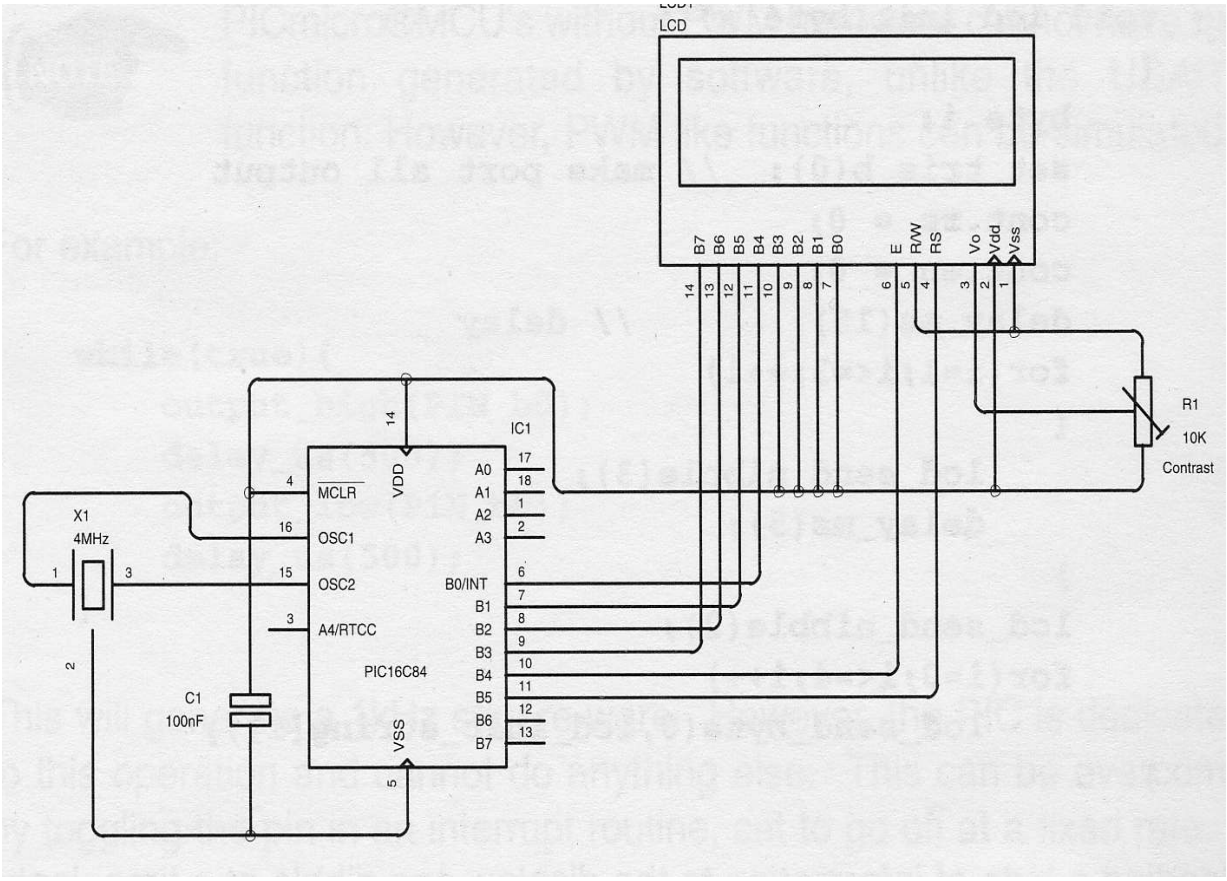
```
{
    byte i;
    set_tris_b(0);   //make port all output
    cont.rs = 0;
    cont.en = 0;
    delay_ms(15);
    for(i=1;i<=3;++i)
    {
        lcd_send_nibble(3);
        delay_ms(5);
    }
    lcd_send_nibble(2);
    for(i=0;i<=4;i++)
        lcd_send_byte(0,lcd_init_string[i]);
}
```

Sending a byte of information to the display, one nibble at a time, looks like:

```
void lcd_send_byte(byte address, byte n)
{
    cont.rs = address;
    delay_cycle(1);
    delay_cycle(1);
    cont.en = 0;
    lcd_send_nibble(n >> 4);   //shift upper nibble 4
places
    lcd_send_nibble(n & 0xf);  //mask off upper nibble
    delay_ms(10);
}
```

The function **`lcd_send_nibble`** does the strobe function:

```
void lcd_send_nibble(byte n)
{
    lcd_data  = n;       //place data on port
    delay_cycle(1);      //delay 1 cycle
    cont.en = 1;         //set enable high
    delay_us(2);         //delay 2us
    cont.en = 0;         //set enable low
}
```



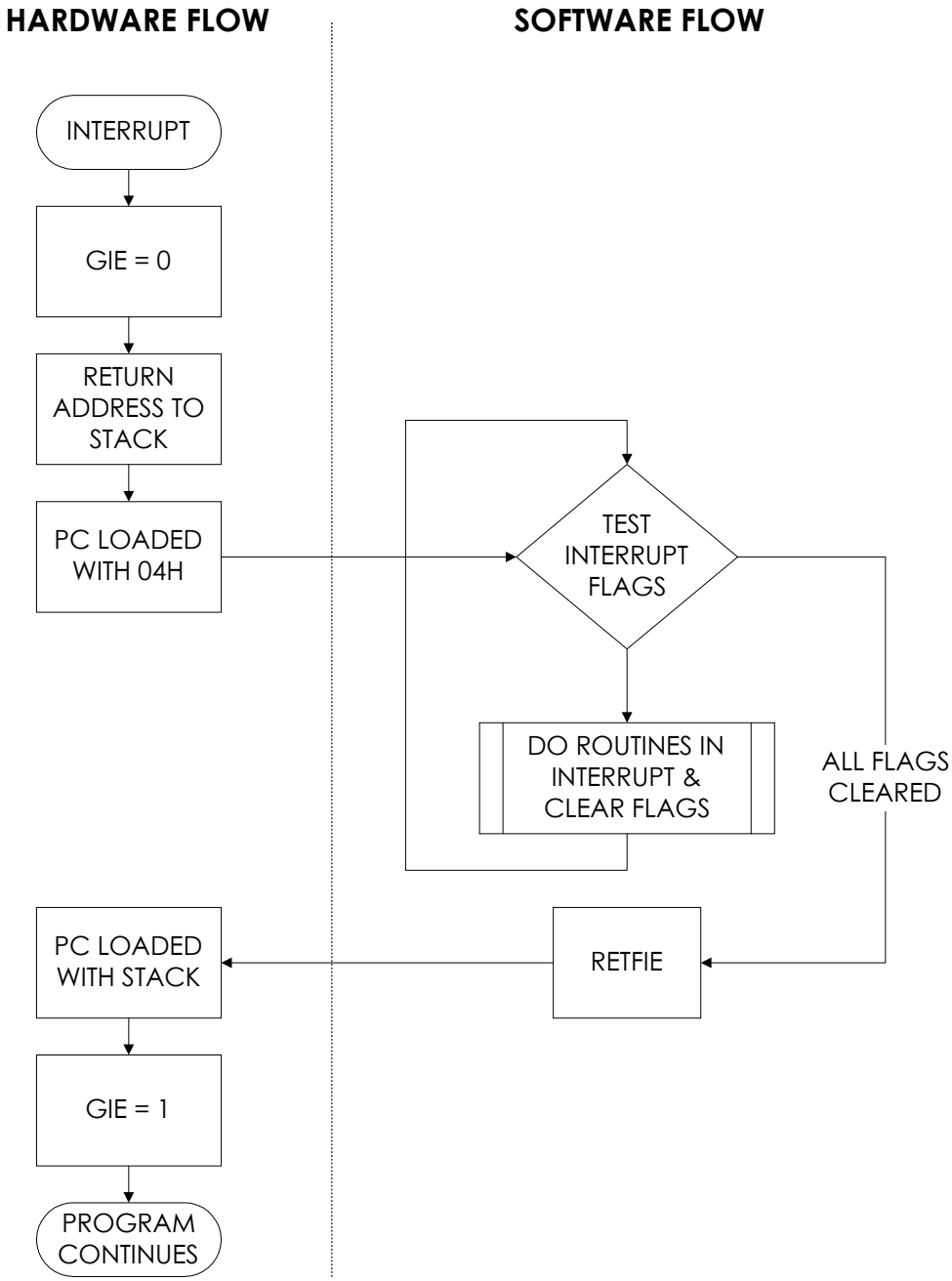
Another function, which is useful when dealing with LCD displays, is the scroll. This is not the built in left/right scroll, but a software scroll up function. The following example is used to place the latest text on the bottom line of a 4 line display, and scroll the previous line and the other 3 up by one. The top line then scrolls off the display and is lost.

```
       byte Line1[0x10];       //setup arrays to hold data
       byte Line2[0x10];
       byte Line3[0x10];
       byte Line4[0x10];
       memcpy(Line1, Line2, 0x10);       //transfer data from
one
       memcpy(Line2, Line3, 0x10);       //array to the next
       memcpy(Line3, Line4, 0x10);       //and again
       memset(Line4, 0x20, 0x10);        //and clear bottom line
       lcd_same_line(0);                 //go to start of
display

       for(i=0;i<==0x0f;++i)
       {
          k = Line1[i];                 //send data from line1
          lcd_send_byte(1,k);           //memory array to display
       }      //repeat for other 3 lines
```

9.11 Interrupts

Interrupts can come from a wide range of sources within the PICmicro® MCU and also from external events. When an interrupt occurs, the PIC hardware follows a fixed pattern as shown below.



The hardware is completely under PICmicro® MCU control, the software is all your responsibility. When an interrupt occurs, the first step is to test and determine if the source is the desired one or, in the case of multiple interrupts, which one to handle first, etc.

Depending on which PIC is used in a design, the type and number of interrupts may vary. The PIC16C5X series have no interrupts, and software written for these products will have to perform a software poll. Some of the interrupt sources are shown below, but refer to the data sheet for latest information.

#priority sets up the order of the interrupt priority:

```
#priority rtcc, rb, tmr0, portb
```

#int_globe - use with care to create your own interrupt handler. The main save and restore of registers and startup code is not generated.

#int_default is used to capture unsolicited interrupts form sources not setup for interrupt action. Examine the interrupt flags to determine which false interrupt has been triggered.

#int_xxx – where xxx is the desired interrupt:

```
#int_rda          //enable usart receive interrupt
rs232_handler()   //interrupt driven data read and store
{
   b=getch();     //load character
   Buffer[Buff+1]=b;    //store character
   Buff++;              //increment pointer
}
enable_interrupts(level);
disable_interrupts(level);
```

This functions set or clear the respective interrupt enable flags so interrupts can be turned on and off during the program execution.

```
ext_int_edge (edge);
```

This is used to select the incoming polarity on PORTB bit0 when used as an external interrupt. The edge can be **1_to_h** or **h_to_1**.

This example forces an interrupt on receipt of a character received via the USART. The character is placed in a buffer and the buffer incremented, ready for the next character. This function is extracted from an LCD display program, as the characters are received faster than the display can handle them.

```
#int_rda          //enable usart receive interrupt
rs232_handler()   //interrupt driven data read and store
{
   b=getch();     //load character
   Buffer[Buff+1]=b;    //store character
   Buff++;              //increment pointer
}
main()
{
   enable_interrupts(INT_RDA);
   enable_interrupts(GLOBAL);
   do { while(True);   }
```

```
}
```

Include Libraries

These libraries add the 'icing on the cake' for C programmer. They contain all the string handling and math functions that will be used in a program. The various libraries are included as, and when, the user requires them.

CTYPE.H contains several traditional macros as follows:

Returns a TRUE if:

isalnum(x)	x is an alphanumeric value i.e. 0-9, 'A' to 'Z', or 'a' to 'z'
isalpha(x)	x is an alpha value i.e. 'A' to 'Z', or 'a' to 'z'
isdigit(x)	x is an numeric value i.e. 0-9
islower(x)	x is an lower case value i.e. 'a' to 'z'
isupper(x)	x is an upper case value i.e. 'A' to 'Z'
isspace(x)	x is an space
isxdigit(x)	x is a hexadecimal digit i.e. 0-9, 'A' to 'F', or 'a' to 'f'

STDLIB.H contains

f = abs(x)	returns the absolute value of x
i = atoi(char *ptr)	returns the ASCII representation of the character as int
i = atol(char *ptr)	returns the ASCII representation of the character as long
i = labs(i)	returns the absolute value of a long integer x

MATH.H holds all the complicated math functions. Examination of this file gives an insight into how the mathematical functions operate. In all cases, the value returned is a floating-point number.

l = sqrt(x)	returns the non-negative square root of the float value x
l = sin(x)	returns the sine value of float x
l = asin(x)	returns the arc sine value of float x
l = tan(x)	returns the tan value of float x
l = atan(x)	returns the arc tan value of float x
l = cos(x)	returns the cos value of float x
l = acos(x)	returns the arc cos value of float x
l = floor(x)	returns the largest value not greater than the value of float x
l = ceil(x)	returns the smallest value not greater than the value of float x
l = exp(x)	returns the exponential value of float x
l = log(x)	returns the log to base e value of float x
l = log10(x)	returns the log to base 10 value of float x

Where Next

What do I need to start development?

The minimum items required to start PICmicro® MCU development work are:

- An IBM compatible PC

- Windows 95, 98, NT, 2000, Me, XP or Linux
- C Compiler

If you then wish to take the development from paper to a hardware design, you will need:

- A programmer – for reliability and support get the PIC® START PLUS Which covers all the PICmicro® MCU devices and is upgradable
- A development board or hardware starter kit – to save time trying to debug software and hardware
- Some EEPROM or Flash part, you will not need an eraser, as the device is electrically erasable (i.e. no window)

Development Path

Zero Cost	Demo versions of the C compiler
Starter	PICSTART PLUS programmer, C compiler, and PIC MCU sample
Intermediate	Microchip ICD for 16F87x family or ICD2 for most Flash PIC MCU
Serious	In Circuit Emulator (ICE). ICEPIC, PIC MASTER, MPLAB ICE2000 or ICE4000 allows debugging of hardware and software at the same time. You will need a programmer to go with the ICE, see a catalog for part numbers.

Pointers to get started

- Start off with a simple program – don't try to debug 2000 lines of code in one go.
- Use known working hardware.
- Have a few flash version of PIC MCU chip on hand when developing to save time for waiting.
- If using PIC® START PLUS (programmer only) you will need to use the program-test-modify process – so allow extra development time.
- Use some form of I/O map when starting your design to speed up port identification and function.
- Draw a software functional block diagram to enable modular code writing.
- Comment on the software as it's written. Otherwise, it is meaningless the following day or if read by another.
- Write, test, and debug each module stage by stage.
- Update documentation at the end of the process.
- ► Attend a Microchip approved training workshop.

What happens when my program won't run?

- Has the oscillator configuration been set correctly when you programmed the PIC?
- Was the watchdog enabled when not catered for in the software?
- Have all the ports been initialized correctly?

- On 16C7X devices, check if the ADCON1 register is configured as analog or digital.
- Ensure the data registers are set to a known condition.
- Make sure no duplication of names given to variables, registers, and lables.
- Is the reset vector correct, especially if code has been moved from one PICmicro® MCU family to another?

Reference Literature

- Microchip data sheets and CDROM for latest product information.
- CCS Reference Manual
- Microchip MPLAB Documentation and Tutorial

Some good reference books on C (in general)

- Turbo C – Kelly & Pohl
- An Introduction to Programming in C - Kelly & Pohl
- C Programming Guide - Purdum
- The C Programming Language – Kernighan & Ritchie

Internet Resource List

- http://www.pic-c.com
- http://www.piclist.com

Contact Information

CCS	http://www.ccsinfo.com
Microchip	http://www.microchip.com

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