CHAPTER 3

Measurement

When people first began to measure things, they used parts of their bodies or other natural objects as measuring units. For example, a *cubit* was the distance from the elbow to the fingertips. Since this distance varied from one person to the next, it was not a very accurate way to measure. Fig. 3-1. Gradually, units became standardized. The Egyptians, for example, had a royal cubit made of black granite. All the other cubit sticks in the land were regularly compared to the royal cubit to make sure they were the same length. From such beginnings came many of the world's measuring systems, including our *customary* system. The customary system is based mostly on traditional English measurements such as the foot and the pound. Fig. 3-2.

In the late 1700s, scientists in France developed the *metric* system. It was based on amounts that were believed to remain constant, such as the size of the earth. Fig. 3-3. This system has been refined and improved and is now known as the SI (modernized) metric system. Today most countries of the world use the metric system. The United States still uses the customary system, but many of our industries have gone metric. You will probably need to know the metric system someday, so it is a good idea to learn to measure in both systems. Fig. 3-4.

THE SI METRIC SYSTEM

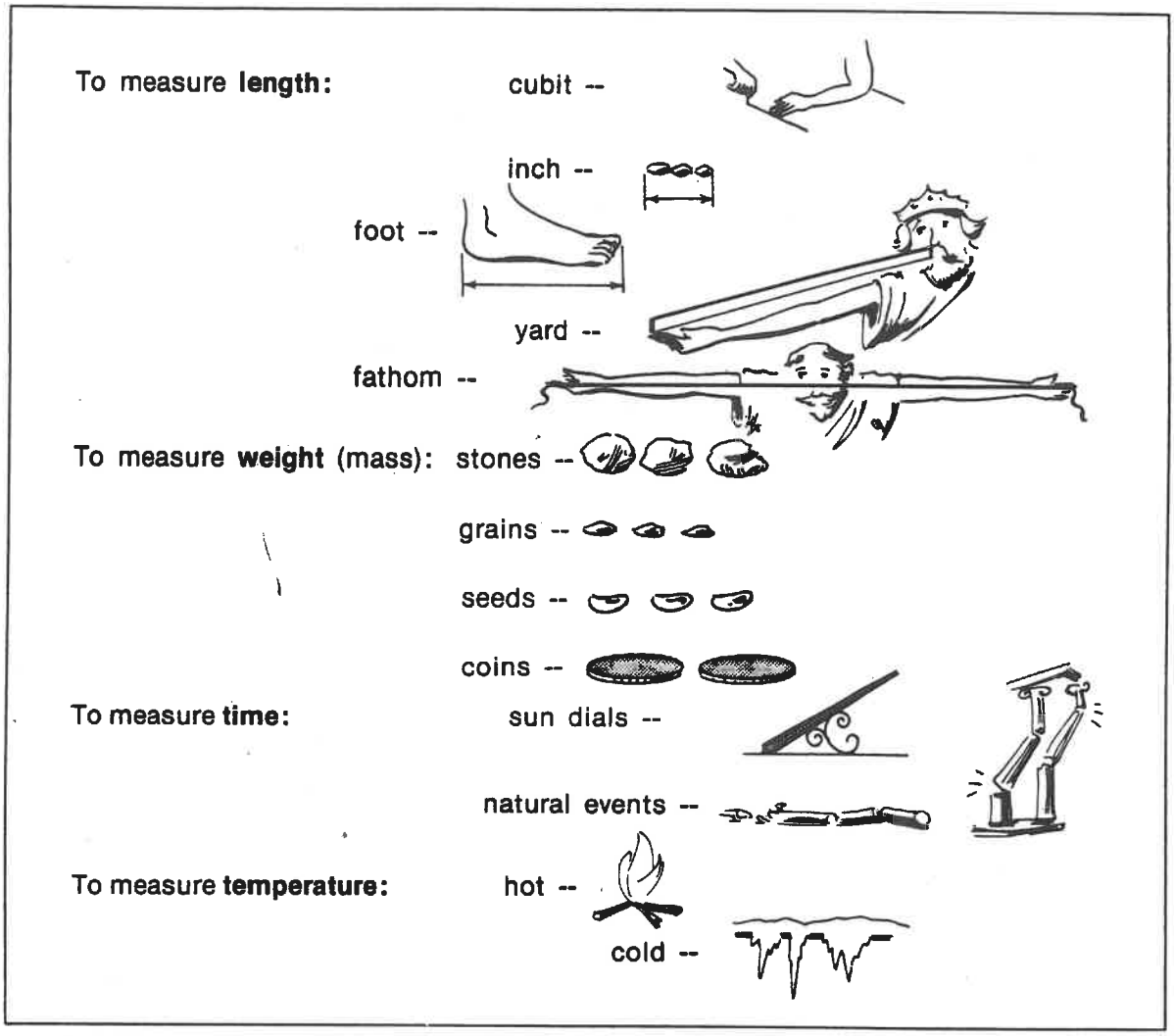
Let's look at the measuring system used by most of the world. The modernized metric system of units, SI, consists of seven *base units.* These are the metre[1], kilogram, kelvin, second, ampere, candela, and mole. Fig. 3-5 (page 32). Other units are derived from these base units. For example, the unit for liquid capacity, the litre[1], is derived from the unit of length, the metre. A litre is the amount of liquid that can be contained in a cube which measures ten centimetres (one-tenth of a metre) on each side.

In everyday life, only four units are used:

- The *metre,* the unit of length, is a little longer than a yard (about 39.37 inches).
- The *kilogram,* the unit of weight (mass), is a little more than two pounds (actually 2.2 pounds).
- The *litre,* the unit of liquid capacity or volume, is a little more than a quart (about 1.06 quarts).
- The *degree Celsius* is the everyday unit for measuring temperature. On the Celsius scale, water freezes at 0°C and boils at 100°C. Degrees Fahrenheit can be converted to degrees Celsius. Subtract 32 from the degrees Fahrenheit and divide by 1.8. If the Fahrenheit temperature is above 50 degrees, there is a faster way to convert. Start with 50°F and 10°C. For every 9 degrees increase in Fahrenheit temperature, add 5 degrees to the Celsius temperature. For example, 59°F is equal to 15°C. A pleasant spring day with a temperature of 68°F (50 + 9 + 9) would be 20°C (10 + 5 + 5).

The metric system is a decimal system. All larger and smaller units are based on multiples of ten, with no fractions. To indicate these larger and smaller units, prefixes are added to the unit words. For example, larger and smaller units of length are indicated by adding such prefixes as *kilo-, centi-,* and *milli-* to the word *metre.* A kilometre is 1000 times larger than a metre. A centimetre is 100 times smaller than a metre (one-hundredth of a metre). A millimetre is 1000

[1]The words *metre* and *litre* can also be spelled *meter* and *liter.*



3-1. ***Here's how people used to make measurements. The* cubit, *for example, was the distance from a bent elbow to the tip of a finger. The* fathom *was the distance between the fingers of outstretched arms. Can you see why these measuring instruments are not very accurate?***

times smaller than a metre (one-thousandth of a metre). These three prefixes are the most common and are used for nearly all units of measurement.

Both the prefixes and the names of the units can be shortened into symbols. Figures 3-6 and 3-7 show the symbols for the most common units and prefixes.

Other Metric Measurements

Speed. Machine speeds are shown in metres per minute (m/min). Highway speed is in kilometres per hour (km/h).

Power. All power is measured in kilowatts (kW). For example, a two-horsepower motor on a saw would be listed as 1.5 kilowatts. One horsepower equals about 0.75 kW.

The customary (English) system used in the United States is called the Imperial system in England.

King Edward I and his successor, Edward II, established legal standards for trading purposes.

Their yard, a metal bar, the unit of length, was called the "iron ulna."

The standard was described as follows:

"And it is to be remembered that the Iron Ulna of our Lord the King contains three feet and no more and the foot must contain twelve inches, measured by the correct measure of this kind of ulna: that is to say, one thirty-sixth part of the ulna makes one inch, neither more nor less."

Another definition from early history:

"It is ordained that three grains of barley, dry and round, make an inch; twelve inches make a foot; three feet make an ulna."

From this early beginning, there developed over 80 standards of weights and measures, most of them with no rhyme or reason. This is why most of the world is changing to the metric system

3-2. ***The customary system developed in England. Today England uses the metric system.***

THE METRIC SYSTEM

During the time of Napoleon, French scientists developed a more accurate system based on earth measurements. It was called the **metric system.** The base unit, the metre, was one ten-millionth (1/10 000 000) of the distance from the North Pole to the equator when measured on a straight line running along the surface of the earth through Paris.

There was a small error in this definition so scientists later defined the metre as the distance between two lines engraved on a special platinum-iridium bar. This bar is kept at the International Bureau of Weights and Measures near Paris.

Still later, the metre was defined in terms of the wavelength of light given off by the krypton-86 atom.

3-3. ***The metric system developed in France. Today most of the world uses the metric system.***

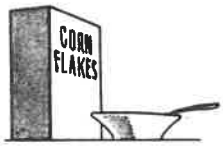
The alarm rings in the morning to wake you. The **time** is 7:30 a.m.

You get up and step on the bathroom scale. Your **weight** (mass) is 60 kilograms (132 pounds).

You look at the outdoor thermometer. The **temperature** is a cool 15 degrees Celsius (59 degrees Fahrenheit).

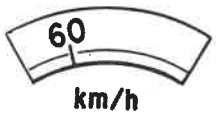
You walk to the door to get the morning paper—a **distance** of 10 metres (33 feet).

Now you're ready for breakfast. Out comes a box of cereal—the big size. The **weight** (mass) is printed on the front as 397 grams (14 ounces).



You open the refrigerator and take out a carton of milk. Its **liquid capacity** is 1 litre (1.06 quarts).

After breakfast you ride to school at a **speed** of 60 kilometres per hour (about 35 miles per hour).

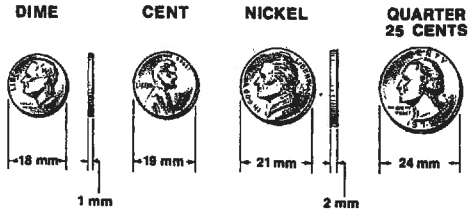


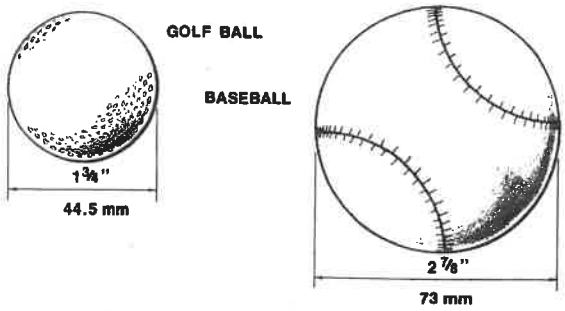
3-4(a). ***All day long you are taking measurements.***

COMPARISON OF CUSTOMARY AND METRIC RULES

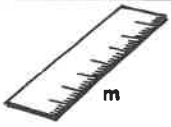
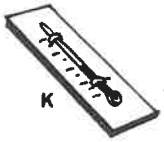
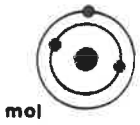
Woodworking rules with customary markings include the 6", 12" (foot), and 36" (yard). Similar rules in the metric system are 150 mm (15 cm), 300 mm (30 cm), and 1 m long. Fig. 3-8.

Let's compare the common 12" rule with the 300-mm metric rule. Fig. 3-9 (page 34). As you saw in Fig. 3-8(a), the 300-mm (30-cm) rule is slightly shorter than the 12" rule. The customary rule is divided into twelve inches, and each inch is





3-4(b). ***You can get a "feel" for metric sizes by remembering the sizes of common things in metric units.***

	Physical Quantity	SI METRIC SYSTEM Base Unit (word and symbol)	Customary (English) or Inch-Pound System Unit (word and abbreviation)
	Length	metre—m	inch, foot, or yard—in, ft, or yd
	Weight (mass)	kilogram—kg	pound—lb
	Temperature	kelvin—K. Used for scientific measurements. Degrees Celsius—°C—is for everyday use.	Fahrenheit—°F
		SAME IN BOTH SYSTEMS	
	Time	second—s	second—s
	Electrical Current	ampere—A	ampere—A
	Luminous Intensity	candela—cd	candela—cd
	Amount of Substance	mole—mol	mole—mol

3-5. ***The base units of the metric system. Note that some units are the same in both the metric and customary systems.***

COMMON METRIC UNITS

Unit	Symbol	Quantity
ampere	A	Electric current
candela	cd	Luminous intensity
degree Celsius	°C	Temperature
gram	g	Weight (mass)
kelvin	K	Temperature (for scientific use)
litre	L	Liquid capacity (volume of fluids)
metre	m	Length
metric ton	t	Weight (mass)—1 t = 1000 kg
second	s	Time
volt	V	Electric potential
watt	W	Power

NOTE: If a unit was named after a person (for example, watt for Scottish inventor James Watt), then the *symbol* for that unit is capitalized. Otherwise, the symbol is lower case. An exception is the symbol for litre, L, which is capitalized so that it won't be confused with the numeral 1.

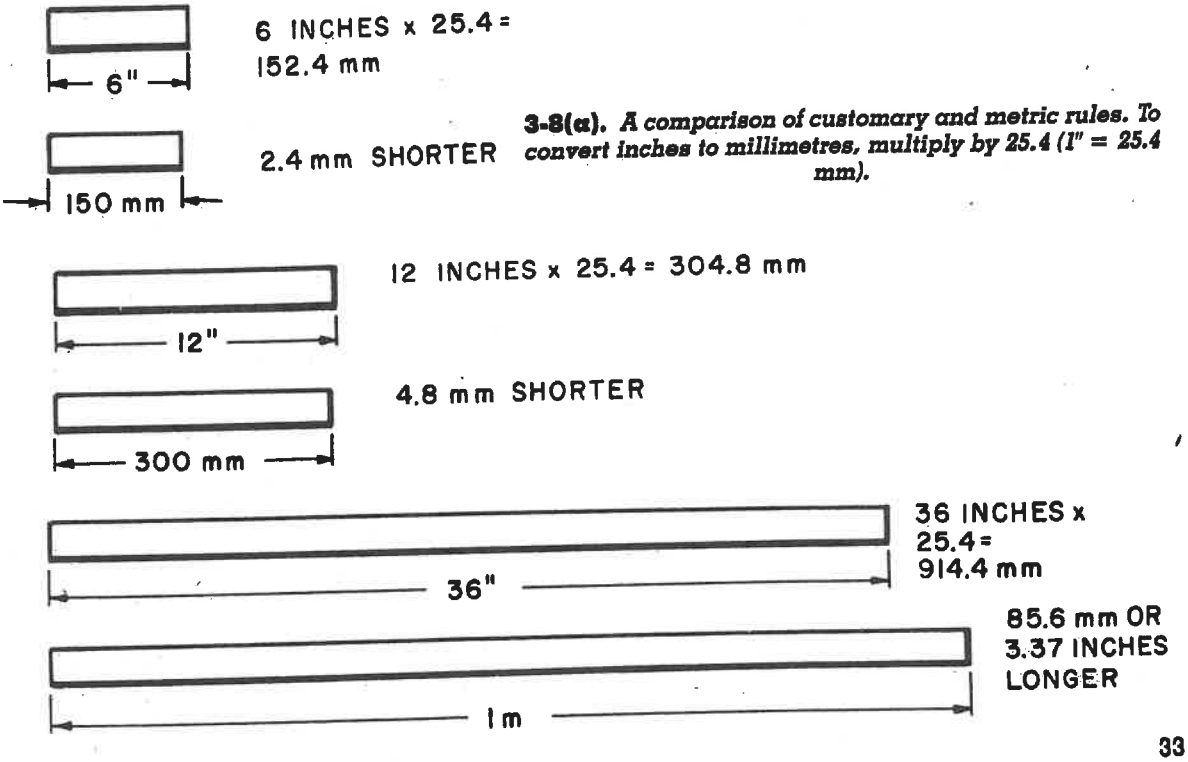
3-6. Some common metric units and their symbols. Note that there is no period after a metric symbol.

COMMON METRIC PREFIXES

Prefix	Symbol	Meaning
giga	G	one billion times
mega	M	one million times
kilo	k	one thousand times
centi	c	one-hundredth of
milli	m	one-thousandth of
micro	μ	one-millionth of
nano	n	one-billionth of

NOTE: Some prefixes are capitalized so that they won't be confused with metric units. For example, G = giga, but g = gram.

3-7. These are the most commonly used metric prefixes. Some examples of how they are used: km = kilometre; cm = centimetre; and mm = millimetre.



3-8(α). A comparison of customary and metric rules. To convert inches to millimetres, multiply by 25.4 (1" = 25.4 mm).

3-8(b). ***This sight-impaired student is comparing a yardstick with a metre rule. Which is longer?***

divided into fractions of either eighths (⅛") or sixteenths (1⁄16"). The metric rule is divided into millimetres. Every tenth line is marked 1, 2, 3, etc., or 10, 20, 30, etc. If the numbers are 1, 2, 3, and so forth, these are centimetre divisions (10 mm = 1 cm). If the rule is marked 10, 20, 30, and so on, these numbered lines represent millimetres. In either case, each of the small divisions is 1 mm.

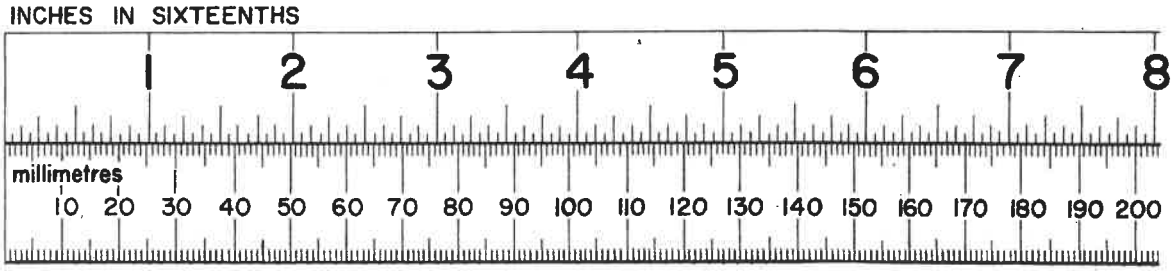
The centimetre rule is harder to use because you often have to change centimetres into millimetres. For example, if there are 3 small divisions beyond the 2, you must think of the 2 cm as 20 mm. Then you must add the 3 small divisions, for a total of 23 mm. On the millimetre rule, you do not have to change units. You simply read three small divisions beyond the 20 as 23 mm. Fig. 3-10.

Note that on the metric rule the smallest division is 1 mm, which is about 1⁄25". The smallest division on the customary woodworking rule is 1⁄16". The 1-mm division is smaller than the 1⁄16" but larger than the 1⁄32" division found on many tape measures and metal rules. For most woodworking using metric dimensions you should measure to the nearest millimetre. This will be more accurate than if you measure to the nearest 1⁄16" in customary dimensions.

Rules are available with three kinds of markings: customary, metric, and metric-customary combination. The metric-customary rule is usually divided into inches and fractions of an inch on one half of the rule and into millimetres and centimetres on the other half.

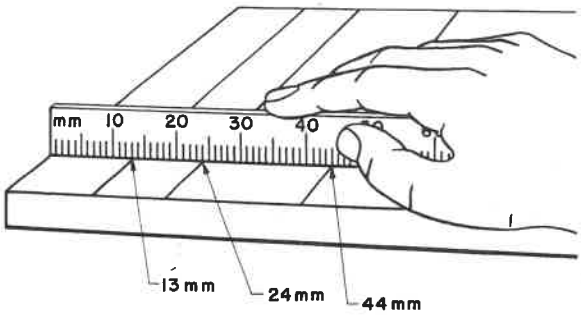
READING A CUSTOMARY RULE

Before using measuring tools, you must be sure that you can use the rule correctly. It isn't hard to measure in feet and exact inches. If the measurement is in feet, you place a single mark (') after the number. If the measurement is in inches, you place a double mark (") after the

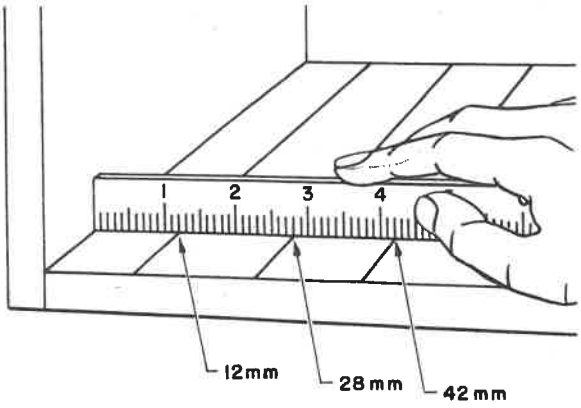


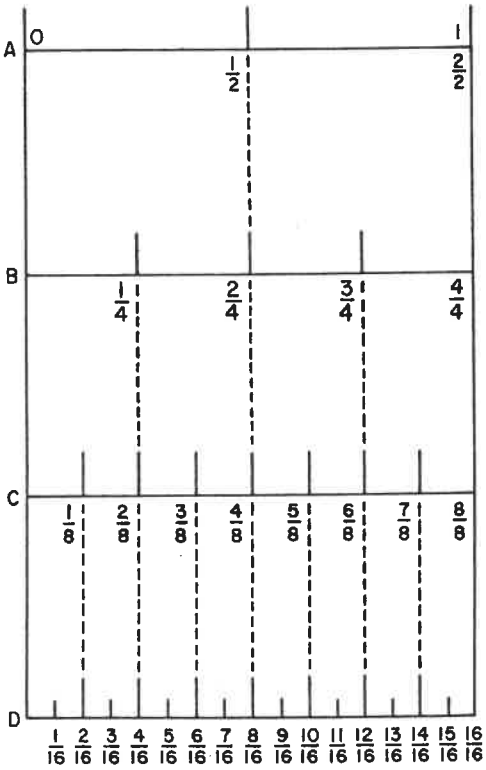
3-9. ***Customary rules are divided into inches and fractions of an inch. Metric rules are divided into centimetres and millimetres.***

3-10(a). ***Measuring with a metric rule that is graduated in centimetres.***



3-10(b). ***It is easier to measure with a metric rule graduated in millimetres.***



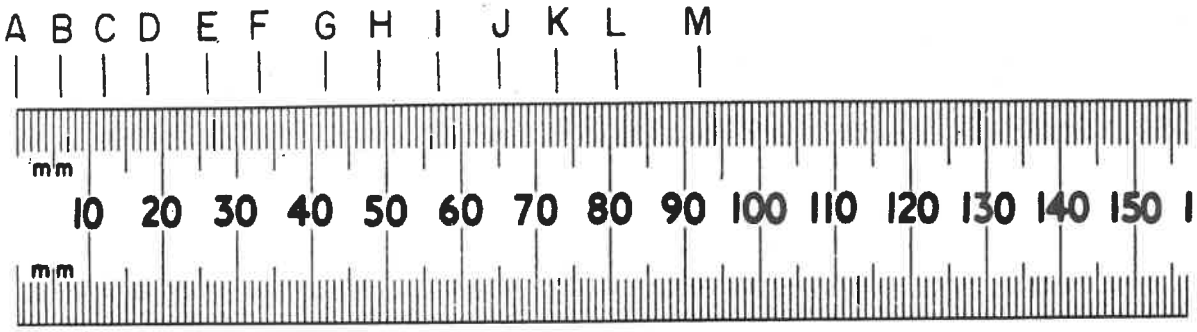


3-11. ***Study this chart. It will help you to read a rule to 1/16".***

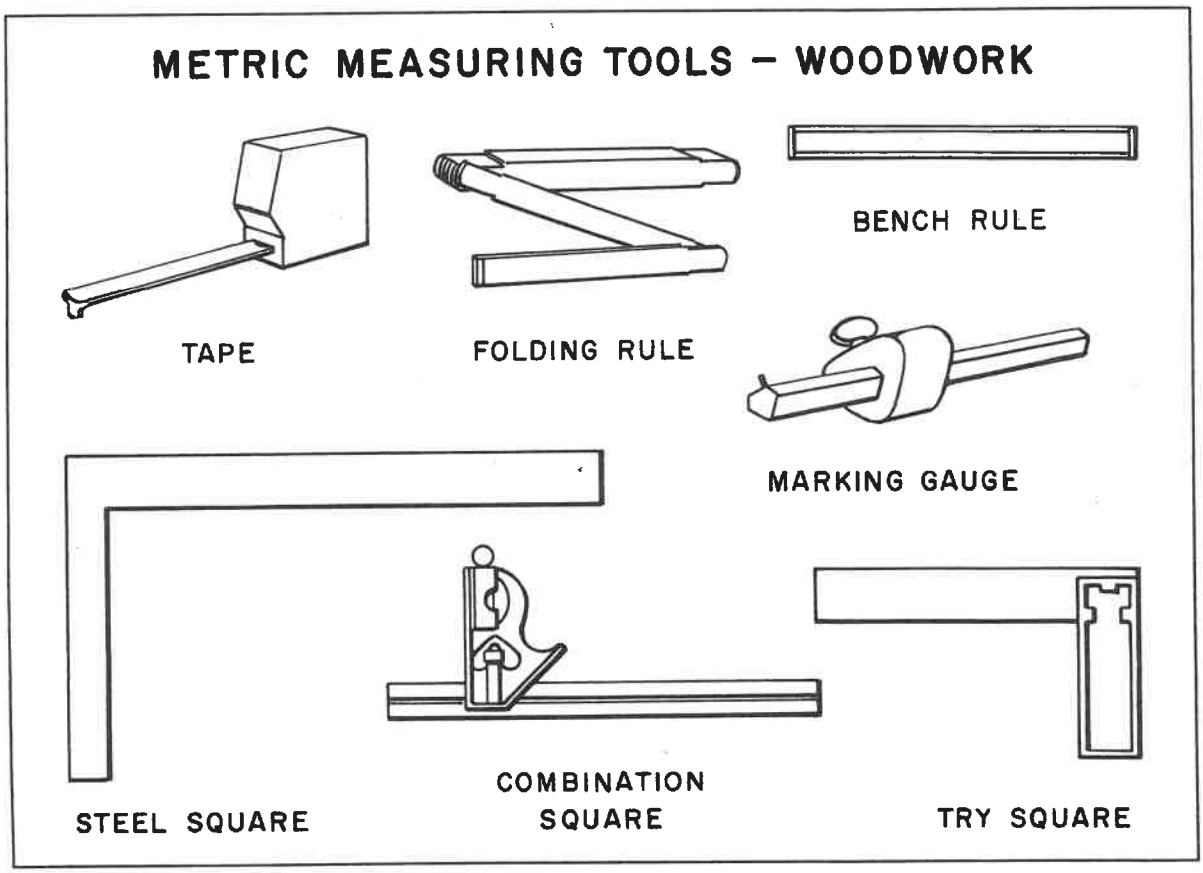
number. You already know that there are 12 inches in a foot and 3 feet (or 36 inches) in a yard.

Measuring in parts (fractions) of an inch takes a little more care.

- Look at the enlarged inch shown in Fig. 3-11. Notice that the distance between 0 and 1 is 1 inch.
- Look at Line A. You see that the inch is divided in half. Each half is ½ inch (½"). This half-inch division line is the longest line between the inch marks on a rule.
- Look at Line B. Here the inch is divided into four equal parts. Each part is ¼". The distance to the first line is ¼", to the second is 2/4", or ½", and to the third is ¾".
- Look at Line C. Here the inch is divided into eight equal parts. Each small division is therefore ⅛". Two of these divisions make 2/8", or ¼", as shown on Line B. Four of these divisions make 4/8", or 2/4", or ½". Some rules used in woodworking are divided into only eight parts, making the smallest division ⅛".
- Look at Line D. Here the inch is divided into sixteen parts. This is usually the smallest division on rules in woodworking. Notice again that 4/16" is equal to 2/8", or ¼". One line past ¼" would be 5/16". On your rule or square, the half-inch mark is the longest line between the inch marks. The ¼" is the next longest, the ⅛" is next, and the 1/16" mark is the shortest.



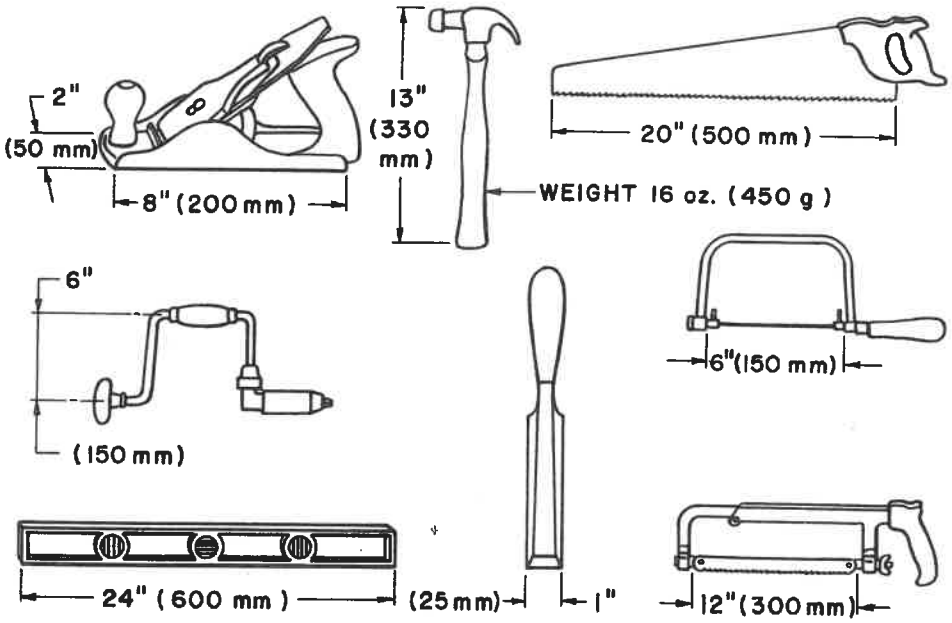
3-12. *Can you read the distance from A to B, A to C, A to D, etc.? Answers are on page 39.*



3-13. *Common measuring tools that need to be replaced to work in metrics.*

TOOLS WHICH WILL NOT NEED REPLACEMENT

METRIC EQUIVALENTS SHOWN ARE THE EXPECTED REPLACEMENT SIZES TO BE AVAILABLE IN THE FUTURE.



3-14. ***Most woodworking tools do not have to be replaced to work in metrics.***

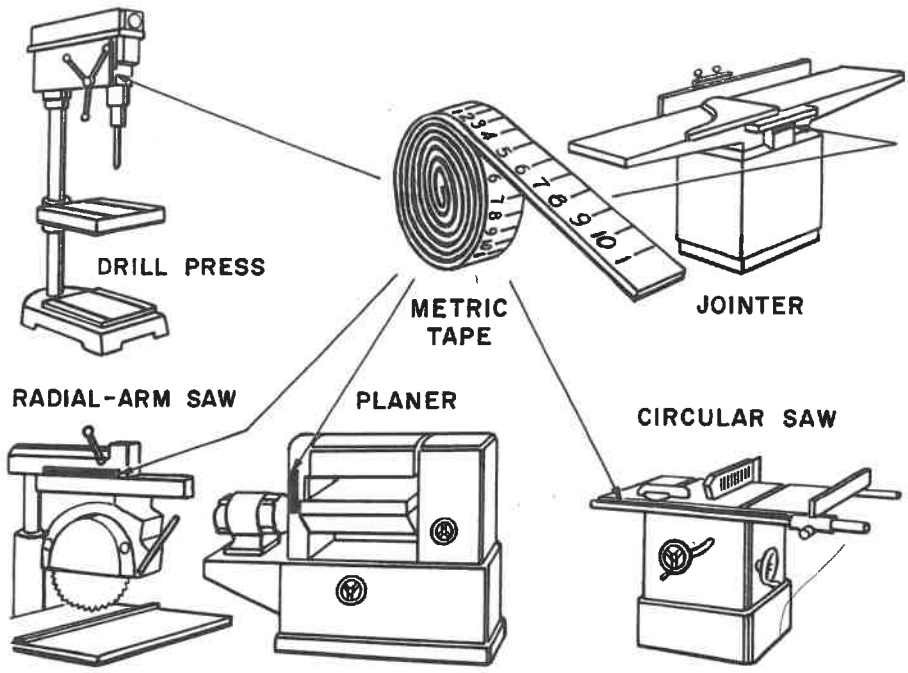
- To read a part, or fraction, of an inch, count the number of small divisions beyond the inch mark. Then see how many divisions there are in the inch on the rule you are using. If there are only eight, for example, and you count five divisions, the measurement is 5/8". If there are sixteen divisions in the inch and you count five, then the measurement is 5/16".
- On scrap paper, draw a line 2¼" long. If your rule is divided into eighths, then the line measures 2 inches plus two small divisions (2/8"). If your rule is divided into sixteenths, then this extra section is 4/16", which is the same as 2/8", or ¼".

READING A METRIC RULE

Like reading the customary rule, this is done by counting the markings. To read the metric rule, count the number of millimetre spaces for a given length. For example, in Fig. 3-12 the length from A to B is 6 mm. The length from A to C is 12 mm. Practice your rule reading by figuring the distances AD, AE, AF, etc. You should also practice measuring nails, screws, lumber, and other common shop objects. Remember to round your measurements to the nearest millimetre.

CONVERTING TOOLS AND MACHINES

It is fairly simple to convert to the metric system in woodworking. The only hand tools that need replacement are rules and other measuring instruments. Fig. 3-13. It is not necessary to replace such tools as planes, drills, or boring bits. Fig. 3-14. Even in countries now going metric,



3-15. ***Gauges and scales on woodworking machines can be converted by pasting metric tape next to or over the customary gauges and scales.***

METRIC CHANGES FOR WOODWORKING

Units of Measurement	millimetre (about 1/25 in.) for all dimensions on drawings —for thickness and width of lumber —for size of panel stock metre (about 10 percent longer than a yard) —for lengths of lumber —for large commercial building litre (about 6 percent more) to replace the quart kilogram (about 2.2 times) to replace the pound
Tool Replacement	All measuring tools—No change in other tools
Machine Changes	Add a metric *scale* (rule) next to the customary scale
Lumber Thickness	¼ inch becomes 6 millimetres ½ inch becomes 12 millimetres 1 inch becomes 25 millimetres
Lumber Lengths	6 feet become 1.8 metres 8 feet become 2.4 metres
Panel Sizes	4 × 8 feet become 1220 × 2440 millimetres
Fasteners	No actual change in size —1-inch nail becomes 25-millimetre nail —2-inch screw becomes 50-millimetre screw
Drills	Metric sizes are available. However, customary sizes are close enough for metric use.

3-16. ***These are the major changes that must be made in woodworking to use the metric system.***

ANSWERS TO FIG. 3–12:

A to B = 6 mm
A to C = 12 mm
A to D = 18 mm
A to E = 26 mm
A to F = 33 mm
A to G = 42 mm
A to H = 49 mm
A to I = 57 mm
A to J = 65 mm
A to K = 73 mm
A to L = 81 mm
A to M = 92 mm

such items as dowels and wood screws are not being changed in actual size. These countries are merely using the metric measurement to identify the tools. For example, a 2″ plane becomes a 50-mm plane, and a 1″ boring bit becomes a 25-mm tool.

Converting woodworking machines is simple. A piece of plastic paste-on metric tape is placed next to or over the customary scale. Fig. 3-15. Figure 3-16 summarizes the changes that need to be made in order to do woodworking in the metric system.

QUESTIONS

1. Which measuring system is more widely used, the metric or the customary?
2. What is the base unit of length in the metric system? The base unit of weight (mass)? The base unit of time?
3. Which is longer, the metre or the yard? Explain.
4. On a 300-mm rule, what is the smallest unit?
5. On customary woodworking rules, what is usually the smallest unit?
6. Do saws, planes, and other hand tools need to be replaced to do work in the metric system? Explain.
7. How can woodworking machines be converted to the metric system?