Chapter 2 Using the SI System in Science

Section 2.1 SI System Units

Terms:

- **Measurement**
- **Precision**
- **Accuracy**

A **measurement** is a repeatable observation of a quantity that includes a number and unit. An estimate is a reasonable guess at a quantity based on observation. When you make measurements, you need to be concerned with two things: precision and accuracy. **Precision** refers to how detailed or exact a measurement is. **Accuracy** refers to the correctness of a measurement.

SI System of Measurement Scientists worldwide agreed to use the **SI system** of measurement in their work. SI stands for “Système Ineternational,” which is French for International System. Each type of measurement in SI has a base unit, such as the meter for distance or the second for time. Prefixes are added to the base unit to show multiples of that unit (such as the kilometer) or fractions of that unit (such as the centimeter). All multiples and fractions used in the SI system are powers of ten.

SI Base Units and Prefixes The first table shows quantities you are likely to measure in your lab work, and the units that describe those quantities.

Quantity	Unit used in SI (symbol)*
Length or distance	meter (m)
Volume	liter (L)
Mass	gram (g)
Density	gram per cubic centimeter (g/cm^3)
Time	seconds (s)
Temperature	degrees Celsius (°C)
Weight	newtons (N)

Prefixes are added to base units to create larger and smaller units for that quantity. There are as many SI units for a quantity as there are unit prefixes. The table below shows common prefixes used in SI measurements and the multiples or fractions of a unit they stand for. In your science work, you will use some of these more than others.

Prefix	Multiple or fraction of a unit	Symbol	Example
kilo-	1000	k	km
hecto-	100	h	hm
deka-	10	da	dam
none (base unit)	1.0		m
deci-	.1	d	dm
centi-	.01	c	cm
milli-	.001	m	mm
micro-	.000001	μ (greek letter, pronounced "mew")	μm

Conversions Sometimes you might change a measurement from one SI length unit to another, or from one mass unit to another, or any quantity. Because SI units are based on powers of 10, you can simply move the decimal point to convert the unit. To get the right answer doing it this way, you need to keep to questions in mind:

1. In which direction do you move the decimal point?
2. How many places do you move the decimal point?

To answer the first question, figure out whether you need to multiply or divide to convert the units.

- When the unit you are changing to is smaller, then there will be more of those units and the number will get larger. The number is getting larger, so you hare multiplying. **Move the decimal point to the right to multiply.**

- When the unit you are changing to is larger, then there will be fewer of those units and the number will get smaller. The number is getting smaller, so you are dividing. **Move them decimal point to the left to the divide.**

To answer the second question, use the prefix chart to figure out how many steps there are between the unit that you have and the unit you want. Then move the decimal point that number of steps. To do this, you will sometimes need to add zeros before or after the measurement.

Example: Convert 15.5 meters into centimeters.

15.5 m = ? cm

1. There will be more centimeters than meters because centimeters are a smaller unit than meters. So the number will be getting bigger. If the number is getting bigger move the decimal place to the right (multiply).
2. There are 100 centimeters to 1 meter, so you multiply by 100. Multiplying by 100 means the decimal point moves 2 places to the right (2 steps on the prefix table). To do this, you may need to add zeroes.

15.5 = 1550cm

Summary:

- **Scientists use the SI System when taking measurements in science.**
- **All measurements include a number and a unit.**
- **To convert a measurement from one SI unit to another SI unit, you move the decimal either left (when dividing), or to the right (when multiplying).**

Section 2.2 Reading Scales

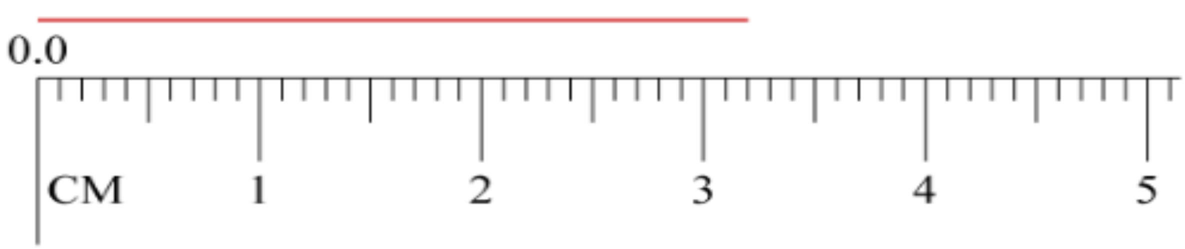
Terms:

- **Mass**
- **Weight**
- **Volume**
- **Meniscus curve**
- **Significant Figures**

Reading Scales

You've probably been using a ruler to measure length since you were in elementary school. But you may have made most of the measurements in English units of length, such as inches and feet. In science, length is most often measured in SI units, such as millimeters and centimeters. Many rulers have both types of units, one on each edge. The ruler pictured below has only SI units. It is shown here bigger than it really is so it's easier to see the small lines, which measure millimeters. The large lines and numbers stand for centimeters. Count the number of small lines from the left end of the ruler (0.0). You should count 10 lines because there are 10 millimeters in a centimeter.

Certain and Uncertain Values When reading scales, we first need the reading of the smallest marked line - the **certain value**, or 'known' value. We finish reading the number with the **uncertain value** or 'guess' value; the space between the two certain lines. The uncertain value is always one order of magnitude less than the certain value. In this example the certain value is the *tenths* of a cm, and the uncertain value would be reported to the *hundredths* of a cm. The units of the measurement are given in cm, the labeled units of the ruler.



Q : What is the certain value?

A : The certain value is .2 cm

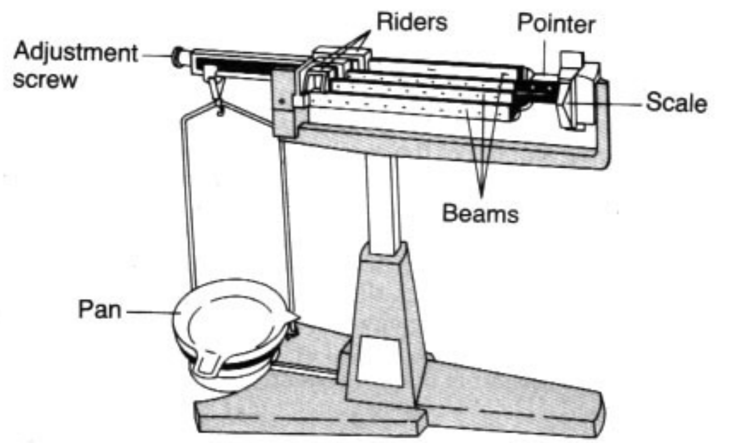
Q: What is the uncertain value?

A: The uncertain value is .20 cm.

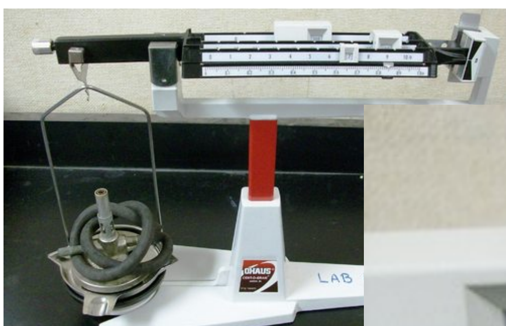
Q : What is the final reading on the scale?

A : The correct reading is 3.20 cm

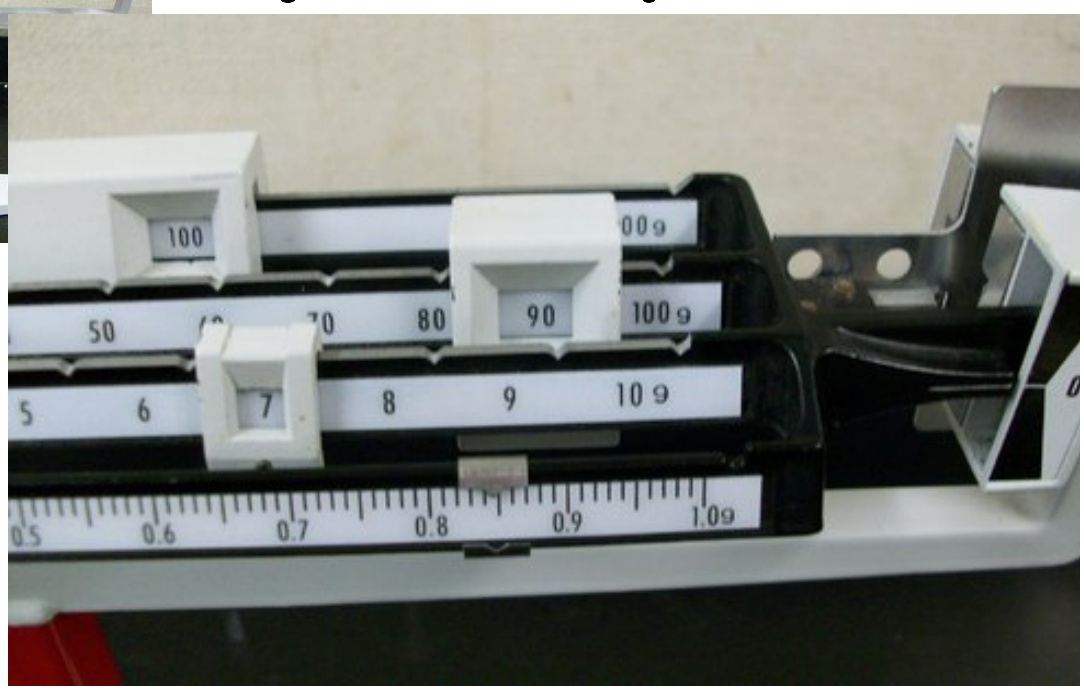
Measuring Mass with a Balance Mass is the amount of matter in an object. Scientists often measure mass with a balance. An example of one type of balance, called a quad beam balance is pictured in the **figure left**. To use this type of balance, follow these steps:



1. Place the object to be measured on the pan at the left side of the balance.
2. Slide the movable masses to the right until the right end of the arm is level with the balance mark. Start by moving the larger masses and then fine-tune the measurement by moving the smaller masses as needed.
3. Read the three scales to determine the values of the masses that were moved to the right. Their combined mass is equal to the mass of the object.



The **Figure below** is an enlarged version of the scales of the quadruple beam balance in **figure above**. It allows you to read the scales. The top scale, which measures the largest movable mass, reads 100 grams. This is followed by the second scale, which reads 90 grams. The third scale reads seven grams, and the bottom and smallest scale is read in three parts; tenths, hundredths, and thousandths of a gram. The printed number is the first decimal (tenths), the smallest line between the printed



numbers (hundredths, also the certain value) is the second decimal, and the uncertain value (thousandths) found between the lines is the third decimal. The smallest beam reads .8 4 to the certain value, and about .84 8 to the uncertain value. Therefore the mass of the object in the pan is 197.848g (100g + 90g + 7g + .8g +. 04g + .008g).

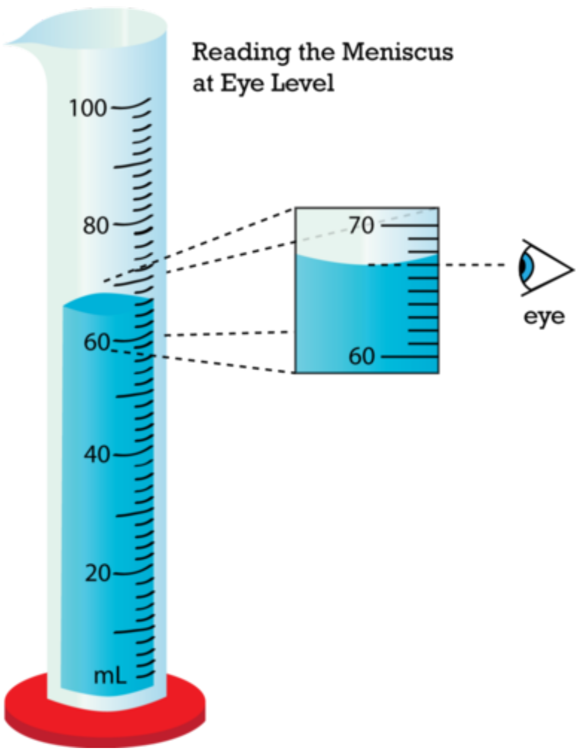
Q: What is the maximum mass this quadruple beam balance can measure?
A: The maximum mass it can measure is 311.00g (200g + 100g + 10g + 1.00g).
Q: What is the smallest mass this triple beam balance can measure?
A: The smallest mass it can measure is one-hundredth (0.01) of a gram.

To measure very small masses, scientists use electronic balances, like the one in the **Figure left.** This type of balance also makes it easier to make accurate measurements because mass is shown as a digital readout. In the picture, the balance is being used to measure the mass of a yellow powder on a glass dish. The mass of the dish alone would have to be measured first and then subtracted from the mass of the dish and powder together. The difference between the two masses is the mass of the powder alone.

Mass vs. Weight Mass is commonly confused with weight. The two are closely related, but they measure different things. **Mass** measures the amount of matter, or stuff, in an object. A balance is used to measure the mass of an object. **Weight** measures the force of gravity acting on an object. The force of gravity on an object depends on its mass but also on the strength of gravity. If the strength of gravity is held constant (as it is all over Earth), then an object with a greater mass also has a greater weight.

The mass of an object is measured in kilograms and will be the same whether it is measured on the earth or on the moon. The weight of an object on the Earth is defined as the force acting on the object by the earth's gravity. If the object were sitting on the moon, then its weight on the moon would be the force acting on the object by the moon's gravity. A spring scale that has been calibrated for wherever the scale is placed measures weight and it reads in Newtons.

Measuring Volume with a Graduated Cylinder **Volume** is a measure of the amount of space that a substance or an object takes up. The volume of a regularly shaped solid can be calculated from its dimensions (LxWxH). In science, the volume of a liquid might be measured with a graduated cylinder. The cylinder in the **Figure left** has a scale in milliliters (mL), with a maximum volume of 100 mL. Volume can also be read in cm ^{3}, as 1 cm ^{3} = 1mL.



Follow these steps when using a graduated cylinder to measure the volume of a liquid:

1. Place the cylinder on a level surface before adding the liquid.
2. After adding the liquid, move so your eyes are at the same level as the top of the liquid in the cylinder.
3. Read the mark on the glass that is at the lowest point of the curved surface of the liquid. This is called the meniscus.

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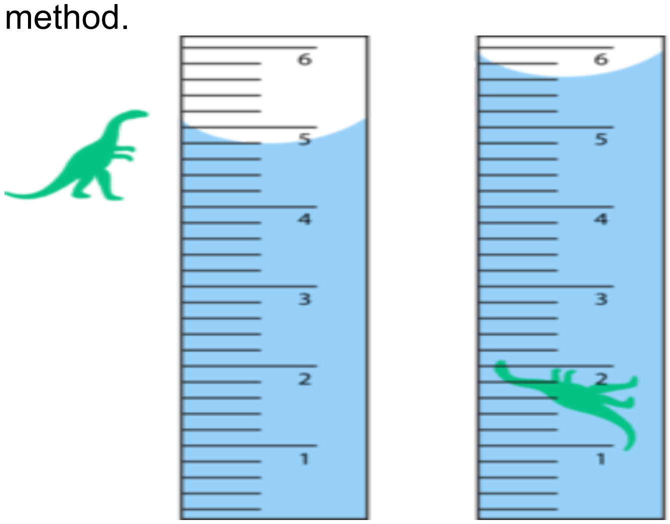
Q: What is the volume of the liquid in the graduated cylinder pictured above?
A: The volume of the liquid is 67.0 mL.
Q: What would the measurement be if you read the highest point of the curved surface of the liquid by mistake?
A: The measurement would be 68.0 mL.

The volume of an irregularly shaped solid can be measured by the displacement method.



Displacement Method for Measuring Volume

1. Add water to a measuring container such as a graduated cylinder. Record the volume of the water.

2. Place the object in the water in the graduated cylinder. Measure the volume of the water with the object in it.

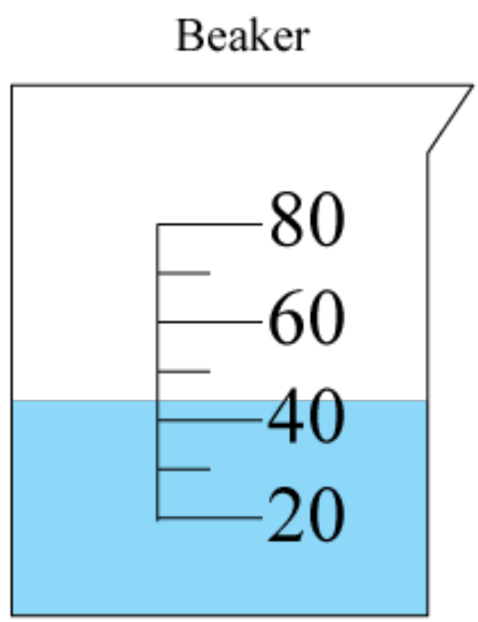
3. Subtract the first volume from the second volume. The difference represents the volume of the object.

What Are Significant Figures?

In any measurement, the number of **significant figures**, also called significant digits, is the number of digits thought to be correct by the person doing the measuring. It includes all digits that can be read directly from the measuring device plus one estimated digit. As you have just read, these digits are referred to as the certain and uncertain value.

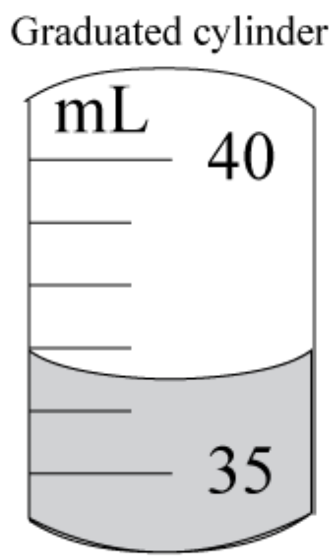
Look at the sketch of a beaker in the **Figure below**. How much blue liquid does the beaker contain? The top of the liquid falls between the mark for 40 mL and 50 mL, but it's closer to 50 mL. A reasonable estimate is 47 mL. In this measurement, the first digit (4) is the certain value and the second digit (7) is an estimate or the uncertain value, so the measurement has two significant figures.

Now look at the graduated cylinder sketched in the **Figure below**. How much liquid does it contain? First, it's important to note that you should read the amount of liquid at the bottom of its curved surface, called the meniscus. This falls about half way between the mark for 36 mL and the mark for 37 mL, so a reasonable estimate would be 36.5 mL.



Q: How many significant figures does this measurement have?

A: There are three significant figures in this measurement. You know that the first two digits (3 and 6) are accurate. The third digit (5) is an estimate. Remember the readability; the 6 is the certain value, and the 5 the uncertain.



Summary:

- **Measurements should always include the certain and uncertain values on a scale.**

Section 2.3 Calculating Derived Quantities

Terms:

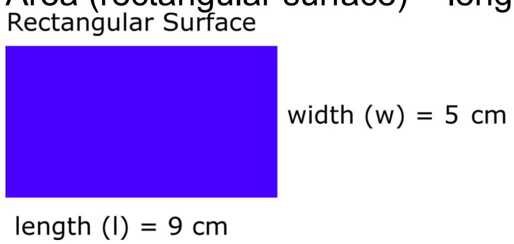
- **Derived quantity**

Derived quantities are quantities that are calculated from two or more measurements. Derived quantities cannot be measured directly. They can only be computed. Many derived quantities are calculated in physical science. Three examples are area, volume, and density.

Calculating Area

The area of a surface is how much space it covers. It's easy to calculate the area of a surface if it has a regular shape, such as the blue rectangle in the sketch below. You simply substitute measurements of the surface into the correct formula. To find the area of a rectangular surface, use this formula:

Area (rectangular surface) = length × width (l × w)



Q: What is the area of the blue rectangle?

A: Substitute the values for the rectangle's length and width into the formula for area:

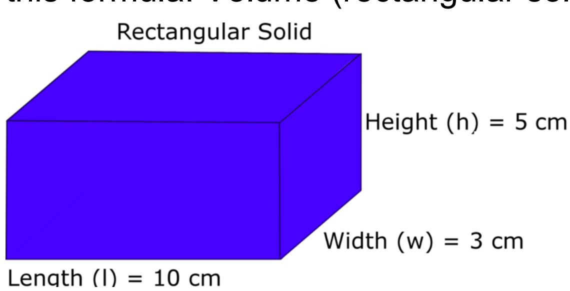
Area = 9 cm × 5 cm = 45 cm^2

Q: Can you use this formula to find the area of a square surface?

A: Yes, you can. A square has four sides that are all the same length, so you would substitute the same value for both length and width in the formula for the area of a rectangle.

Calculating Volume

The volume of a solid object is how much space it takes up. It's easy to calculate the volume of a solid if it has a simple, regular shape, such as the rectangular solid pictured in the sketch below. To find the volume of a rectangular solid, use this formula: Volume (rectangular solid) = length × width × height (l × w × h)



Q: What is the volume of the blue rectangular solid?

A: Substitute the values for the rectangular solid's length, width, and height into the formula for volume:

Volume = 10 cm × 3 cm × 5 cm = 150 cm^3

Calculating Density

Density is a quantity that expresses how much matter is packed into a given space. The amount of matter is its mass, and the space it takes up is its volume. To calculate the density of an object, then, you would use this formula:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Q: The volume of the blue rectangular solid above is 150 cm ^{3}. If it has a mass of 300 g, what is its density?

A: The density of the rectangular solid is:

$$\text{Density} = \frac{300 \text{ g}}{150 \text{ cm}^3} = 2 \text{ g/cm}^3$$

Q: Suppose you have two boxes that are the same size but one box is full of feathers and the other box is full of books. Which box has greater density?

A: Both boxes have the same volume because they are the same size. However, the books have greater mass than the feathers. Therefore, the box of books has greater density.

Units of Derived Quantities

A given derived quantity, such as area, is always expressed in the same type of units. For example, area is always expressed in squared units, such as cm ^{2} or m^2. Volume is expressed in cubed units, such as cm ^{3} or m ^{3}.

Q: A certain derived quantity is expressed in the units kg/m ^{3}. Which derived quantity is it?

A: The derived quantity is density, which is mass (kg) divided by volume (m ^{3}).

Summary:

- **Derived quantities are quantities that are calculated from two or more measurements. They include area, volume, and density.**
- **The area of a rectangular surface is calculated as its length multiplied by its width.**
- **The volume of a rectangular solid is calculated as the product of its length, width, and height.**
- **The density of an object is calculated as its mass divided by its volume.**
- **A given derived quantity is always expressed in the same type of units. For example, area is always expressed in squared units, such as cm ^{2}.**