**Notes about Measurement, Accuracy and Precision**

* The ***ACCURACY*** of a measurement refers to how close the measurement is to the actual or accepted value of the quantity measured.
* The ***PRECISION*** is the degree of detail to which a measurement is given. For example is a length given to the nearest cm or mm?
* A measurement is considered ***VALID*** if it is both accurate and precise.
* It is a common mistake to think that if you report a measurement, or answer a question with more decimal places in your answer that you are giving more accurate and precise results. ***THIS IS INCORRECT***. In fact it is actually misleading to report any more digits than those about which we are confident.

**ACCURACY**

The accuracy of a measurement depends upon the method used to determine the measurement. In general the more carefully the measurement is taken, the more accurate the result will be. The accuracy of a measurement can only be known if there is some accepted or known value to compare it to.

**Example:**  Let’s say you’d like to measure the number of people attending a concert in a large auditorium. You cannot count every person, so you come up with a clever idea. You notice that the floor is covered with large tiles and you see that each tile has about three people standing on it. You are able to see that the rectangular room is 20 tiles wide and 40 tiles long. So you multiply and find that there are 20 x 40 = 800 tiles. With three people standing on each tile, that means there are 2400 people in the room. After the concert you find out that there were actually 2546 people at the concert. Your result is not the same as the actual value, and so it is not perfectly ACCURATE.

Accuracy can be described in terms of ABSOLUTE ERROR, or the difference between a measurement and the actual value. Error is usually expressed as a positive value, so we use the absolute value of the difference:

$$Absolute Error=\left|Measured Value-Actual value\right|=146 people$$

**Notice that the absolute error is reported with units (in this case people).**

Error can be expressed as a percent of the actual or real value, called PERCENT ERROR. Percent error is calculated like this:

$$Percent Error=\frac{\left|Measured Value-Actual value\right|}{Actual Value}×100\%= \frac{Absolute Error}{Actual Value}×100\%$$

$$=\frac{146 people}{2546 people}×100\%= 5.7\%$$

**Notice that percent error does not have units.**

**Example 2:** Students conduct an experiment in a physics class to measure the strength of the Earth’s gravitational field (we will do such an experiment later this year). From the experiment the students obtain a value of 11N/kg. The accepted value for the Earth’s gravitational field is 9.8N/kg.

Find the absolute error and the percent error.

$$Absolute Error=\left|Measured Value-Actual value\right|=1.2N/kg$$

$Percent Error=\frac{\left|Measured Value-Actual value\right|}{Actual Value}×100\%$=$\frac{1.2N/kg}{9.8N/kg}×100\%$ = 12%

**PRECISION**

Whenever a quantity is measured there is some uncertainty in the measurement. The amount of detail that you can CONFIDENTLY and CONSISTANTLY state in a measurement is the precision. This is determined by your measurement device, your technique and the quantity being measured.

In simplest terms the PRECISION tells you how many decimal places you know the measurement to.

EXAMPLE 1: What is the measurement shown below?





* We can see that the measurement is between 6.3cm and 6.4cm.

* We need to ESTIMATE the final digit.
* If we look closely we can see that the measurement is closer to 6.3cm than to 6.4cm. We will report this measurement as 6.32cm. (It would be possible to estimate this as 6.31cm or 6.33cm, the final digit is AN ESTIMATE).
* The measurement is precise to **0.01cm.** This tells you the PLACE VALUE of the ESTIMATED DIGIT. The 2 in 6.32 occupies the hundredths ($\frac{1}{100}$ or .01) place.
* We CANNOT estimate beyond one digit. For example you cannot report the measurement to be 6.325cm as this has two digits (6.3**25**cm) beyond the final certain digit.

**THE FINAL DIGIT REPORTED IN THE MEASUREMENT IS AN ESTIMATE.**

When we see the measurement 6.32cm we need to understand that what we know is that the measurement is between 6.3cm and 6.4cm, and that it is estimated to be 6.32cm.

EXAMPLE 2:

You are given a measured value for the mass of a motorcycle. The mass is given as 226kg.

Look at the number: 22**6**kg

The final digit 6 is the estimated digit.

This means we know FOR CERTAIN that the measurement is between 220kg and 230kg.

All reported digits including the estimate are considered to be precise. This number is precise to the ONES or to 1kg.

* From this we can determine that the mass is between 220 kg and 230 kg
* The final digit 6 is **AN ESTIMATE**.
* This measurement is precise to 1 kg

EXAMPLE 3:

You are told a cannon-ball flies 94.2m from where it is fired to where it lands.

* From this we know the cannon ball travels between 94 m and 95 m
* The final digit, 2 , is **AN ESTIMATE**.
* This measurement is precise to 0.1 m

EXAMPLE 4

The length of a bus is 11.48m.

* From this we can determine that the length is between 11.4 m and 11.5 m
* The final digit 8 is **AN ESTIMATE**.
* This measurement is precise to .01 m

EXAMPLE 5

A water balloon filled with cooked spaghetti noodles has a mass of 1.26kg

* From this we can determine that the mass is between kg and kg
* The final digit is **AN ESTIMATE**.
* This measurement is precise to kg

EXAMPLE 6

The speed of a car is determined to be 28m/s.

* From this we can determine that the speed is between m/s and m/s
* The final digit is **AN ESTIMATE**.
* This measurement is precise to kg

EXAMPLE 7:

What mass is indicated by the arrow below?

2400g 2500g 2600g

The mass is between 2400g and 2500g. We need to ESTIMATE the final digit. Our final answer should be precise to 10g. The arrow is much closer to 2400g than 2500g. My estimated digit needs to be the TENS digit.

I estimate **2420g.**

* From this we know the mass is between \_\_\_\_\_\_\_\_\_\_\_g and \_\_\_\_\_\_\_\_\_\_\_\_\_g
* The digit, \_\_\_\_\_\_\_, is **AN ESTIMATE**.
* This measurement is precise to \_\_\_\_\_\_\_\_\_\_\_\_\_g

So far this is pretty straight forward. There is one thing to be careful of. Zeros.

EXAMPLE 8:

You are told that a cat has a mass of 2400g, what does that mean?

* The zeros at the end of this number are called place-holders.
* The job of theses zeros is to give place value to the 2 and the 4.
* In the number 2400g, the 2 represents 2 “thousands” and the 4 represents 4 “hundreds” we know this because of the zeros at the end of the number. They are not measured zeros.

It is understood that the measurement 2400g represents a value between 2000g and 3000g and that the final MEASURED digit, 4, is the ESTIMATED digit. So this measurement is precise to 100g.

* From this we know the mass is between \_\_\_\_\_\_\_\_\_\_\_g and \_\_\_\_\_\_\_\_\_\_\_\_\_g
* The digit, \_\_\_\_\_\_\_, is **AN ESTIMATE**.
* This measurement is precise to \_\_\_\_\_\_\_\_\_\_\_\_\_g

EXAMPLE 9:

What mass is indicated by the arrow below?

2400g 2500g 2600g

The mass is between 2400g and 2500g. We need to ESTIMATE the final digit. Our final answer should be precise to 10g. The arrow is much closer to 2400g than 2500g.

In fact, it is clear that the mass is closer to 2400g than to 2410g.

HOWEVER…

WE CANNOT REPORT A MASS OF 2402g or 2403g, AS THESE ARE TOO PRECISE.

* We can only estimate **one digit beyond the precision of the measuring device**. So I think the mass is **240**0g. But the 4 is not estimated, the 0 next to the 4 is the estimate. How can I show this?

Use scientific notation!

* The measurement 2400g can be written as 2.4 x103g. In this case you notice the place-holder zeros disappear.
* To show 2400g, precise to 10g write 2.40 x 103g. Now the final zero is not showing place value, its reason for being there is to show the precision of the measurement!

So,

* 2400g is understood to be between 2000g and 3000g, with the 400g being the estimate. This measurement is precise to 100g.
* 2.4 x 103 is understood to be between 2000g and 3000g, with the 400g being the estimate. This measurement is precise to 100g.
* 2.40 x 103 is understood to be between 2400g and 2500g, with the 00g being the estimate. This measurement is precise to 10g.
* 2.400x103 is understood to be between \_\_\_\_\_\_\_\_g and \_\_\_\_\_\_\_g, with the \_\_\_\_\_\_\_g being the estimate. This measurement is precise to \_\_\_\_\_\_g.

EXAMPLE 10:

0cm 100cm

a. What is the location of the arrow?

b. What is the location of the arrow?

0cm 100cm

QUESTIONS WITH ACCURACY

1. A student measures the mass of a leather glove filled with SPAM to be 530g. The actual mass is determined

to be 498g.

 a. What is the absolute error?

 b. What is the percent error?

2. An average chicken egg has a mass of 50g. You weight a bag of chicken eggs and find a mass of 1630g.

 a. How many eggs do you expect to find in the bag?

Upon counting you find that the bag contains 29 eggs.

 b. What is your absolute error?

 c. What is your percent error?

 d. Give a plausible explanation for the discrepancy.

3. Greek philosopher/scientist Eratosthenes measured the circumference of the earth in the year 240 BC (1732 years before Columbus sailed). His equipment was: a hole in the ground, a stick, the shadow made by sunlight, and very keen reasoning. His results were amazingly accurate. In his calculations, he used a unit of distance called a **stadia**. There is some controversy about the accuracy or Eratosthenes’s results.

a. If we assume that Eratosthenes used the most common unit for stadia, then his measurement for the earth’s circumference (converted to kilometers) is 46,620 km. The accepted value is 40,041.47 km. What is the percent error?
b. If we assume that he used a less common *Egyptian Stadia* as his unit for length, his result would be 39,690 km. What, in this case, would be the percent error?

QUESTIONS WITH PRECISION

A. 15060.89g This value is known to be between **15060.8g** and **15060.9g**

This value is precise to **0.01g**

B. 107.1 m This value is known to be between **107m** and **108m**

This value is precise to **0.1m**

C. 1200 g This value is known to be between **\_\_\_\_\_\_\_\_\_** and **\_\_\_\_\_\_\_\_\_\_**

This value is precise to **\_\_\_\_\_\_**

D. 62cm This value is known to be between **\_\_\_\_\_\_\_\_\_** and **\_\_\_\_\_\_\_\_\_\_**

This value is precise to **\_\_\_\_\_\_**

E. 0.0256kg This value is known to be between **\_\_\_\_\_\_\_\_\_** and **\_\_\_\_\_\_\_\_\_\_**

This value is precise to **\_\_\_\_\_\_**

F. 1.245s This value is known to be between **\_\_\_\_\_\_\_\_\_** and **\_\_\_\_\_\_\_\_\_\_**

This value is precise to **\_\_\_\_\_\_**

G. 200m This value is known to be between **\_\_\_\_\_\_\_\_\_** and **\_\_\_\_\_\_\_\_\_\_**

This value is precise to **\_\_\_\_\_\_**

H. 2.0x102m This value is known to be between **\_\_\_\_\_\_\_\_\_** and **\_\_\_\_\_\_\_\_\_\_**

This value is precise to **\_\_\_\_\_\_**