

Laboratory Exercise: *SI* Unit Standards

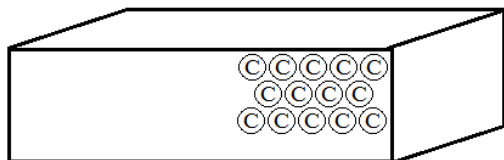
In this short exercise we will use some crude physical measurements to crudely estimate quantities such as Amount and Light Intensity in terms of base *SI* units. For this exercise, we will be careful to report all of our measurements and estimates in terms of the following *SI* units exclusively:

<u>Quantity</u>	<u>Base Unit</u>	<u>Quantity</u>	<u>Derived Unit</u>
Length	meter (m)	Volume	meter ³ (m ³)
Mass	kilogram (kg)	Charge	coulomb (C)
Current	ampere (A)	Illuminance	lux (lx)
Time	second (s)	Luminous Flux	lumen (lm)
Amount	mole (mol)	Solid Angle	steradian (sr)
Luminous Intensity	candela (cd)		

Specifically, we will measure the number of moles of Carbon atoms contained in a Graphite sample, the number of moles of Electrons delivered to a household box fan while it operates over a period of time and the luminous intensity of a candle's flame.

Moles Carbon Atoms

In order to estimate the number of Carbon atoms in a Graphite sample, we will measure the geometric dimensions of the sample. This will allow us to determine its volume; to be reported in the *SI* unit meter³. The volume of an individual Carbon atom in the sample can be determined using a previous estimate of its diameter (1.54×10^{-10} m), assuming the atom is spherical:



Graphite

$$V_{\text{sphere}} = \frac{4}{3} \pi \left(\frac{\text{dia}}{2} \right)^3$$

(At this point it should be noted that Carbon atoms in different materials will have slightly different diameters. We are working with an estimate of the average diameter from a large number of materials composed of Carbon atoms.)

We can determine the number of Carbon atoms in the sample from these volumes, but a complication enters the picture. Packing spheres into a rectangular volume is not 100% efficient. In fact, for the Carbon atoms packed into Graphite it is only about 22% efficient. So, we must estimate the volume of the Graphite sample actually occupied by the Carbon atoms. Then, the ratio of this volume to the volume of the Carbon atom will give us the number of Carbon atoms in the sample:

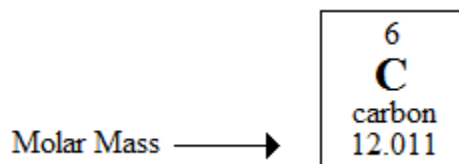
$$\# \text{ C atoms} = \frac{\text{Volume Graphite Occ.by C Atoms}}{\text{Volume Carbon Atom}}$$

This, in turn, will allow us to determine the number of moles of Carbon atoms contained in the sample. Finally, the ratio of the mass of the sample to the number of moles will give us the Molar Mass of Carbon:

$$\text{Molar Mass C} = \frac{\text{Mass Graphite Sample}}{\text{Moles C Atoms in Graphite Sample}}$$

This is a key physical property of any elemental substance and is typically reported in units of *grams/mole* in the Periodic Table of the Elements.

We will compare our estimate of the molar mass of Carbon with that reported in the Periodic Table.



Moles Electrons

In order to estimate the number of moles of electrons delivered to an operating fan, we will measure the electric current (I) flowing to the fan over a period of time using a *Kill A Watt EZ* P4660 meter manufactured by P3 International. The meter is installed into a power outlet and the device whose power consumption is to be measured is plugged into the meter. The meter then monitors the current flow to the operating device from the power source.



By definition, the charge (Q) delivered by power source is then:

$$Q = I \times T$$

where T is the time of operation of the device. If the current is measured in *SI* units of amperes and T in seconds, then Q is reported in *SI* units of coulombs.

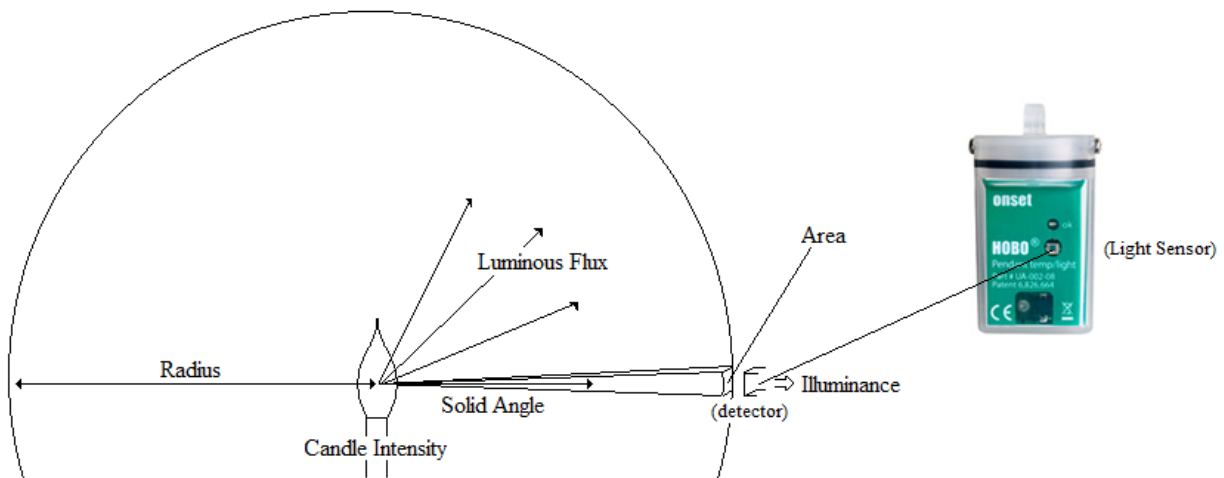
Because the current flow is due to an opposite flow of electrons, the number of electrons delivered during the time the device is operating is simply the ratio of the charge delivered to the electric charge of an electron:

$$\# \text{ electrons} = \frac{Q}{\text{Charge of Electron}}$$

In a series of very elegant and tedious measurements that we will discuss later in the course, Robert Millikan was able to determine the charge of an electron. The currently accepted value for this quantity is $-1.60217647 \times 10^{-19}$ coulombs. This determination will then allow for an estimation of the number of moles of electrons delivered during the fan's operation.

Candelas

In our last estimation we will determine the intensity of a candle's flame by measuring the Illuminance, in *SI* units of Lux, using the light sensor of a UA-002-008 *Hobo Pendant Data Logger*. The measurement will be very crude indeed as the sensor's specifications report, "The light sensor is most useful for determining relative changes, rather than absolute values of intensity." Not to be deterred, we will use the sensor to determine the Luminous Intensity of the candle anyway; we simply expect a very large percentage error for our result.



As pictured above, the Luminous Flux from a candle's flame can be determined from the Illuminance measurement of the light sensor by:

$$\text{Luminous Flux} = \text{Illuminance} \times \text{Detector Area}$$

If the detector's operational sensing area is reported in units of meter², then the luminous flux will be calculated in *SI* units of lumens. The candle's Luminous Intensity is then estimated by determining the luminous flux of the light within a solid angle defined by the detector's operational area:

$$\text{Luminous Intensity} = \frac{\text{Luminous Flux}}{\text{Solid Angle}}$$

The solid angle (Ω) is defined by the Area of the detector, in this case, per area of the sphere of radius (R) defined by the position of the sensor. So,

$$\Omega = \frac{\text{Detector Area}}{4 \pi R^2}$$

Measured in this manner, Ω is reported in the *SI* unit steradian.

We can expect the luminous intensity of a candle's flame to be about one candela. However, remember we are really pushing beyond our sensor's specifications and so the resulting estimate will be severely in error.

Procedure, Data & Data Analysis

Report all measurements and calculated results in terms of fundamental SI units. Use appropriate abbreviations for all reported values.

The Mole

A Mole of Carbon Atoms

1. Obtain a piece of geometrically regular Graphitic Carbon. **Handle this with gloves, otherwise you will smear Graphite everywhere.** Use a simple ruler to measure the dimensions of the object.
2. **Using a weigh boat on the analytical balance,** measure the mass of your Carbon sample.

Data

Dimensions _____ x _____ x _____

Mass _____

Data Analysis

Calculate the Volume of Your Graphite Sample and the Volume of the Sample Occupied by Carbon Atoms:

Calculate the Volume of a Carbon Atom:

Calculate the Number of Moles Carbon Atoms in Your Graphite Sample:

Calculate the Molar Mass of Carbon and Your Percentage Error:

A Mole of Electrons

1. Proceed to a workstation set-up with a household box fan, a *Kill A Watt* meter and a stopwatch. Simply turn on the fan and note how fast the current increases to meet the fan's load. Allow the fan to operate for 100 seconds and note the current draw. Then, turn the fan off and again note how quickly the current draw drops to zero.

Data

Time to Max. Current Draw _____

Current Draw of Fan _____

Time to Zero Current Draw _____

Data Analysis

Calculate the Charge Delivered to the Fan while it was Operating:

Calculate the Number of Moles of Electrons Delivered to the Fan while it was Operating:

The Candela

1. Measure the approximate dimensions of the light sensing unit of your *Hobo Pendant Data Logger* in units of meters.
2. Proceed to the Dark Room with your *Hobo Pendant Data Logger*.
3. Clamp the sensor into place about 0.5 meters from a standard candle, at about the same height as the candle, with the light sensing unit pointed squarely toward the candle.
4. Light the candle, turn on the sensor and turn off the room lights. Collect data for about one minute.
5. Turn on the room lights and shutoff the sensor.
6. Examine the data output of the sensor. Estimate the illuminance, in units of Lux, of the candle.

Data

Dimensions _____ x _____

Dist. from Candle _____

Approx. Illuminance _____

Data Analysis

Calculate the Area of the *Hobo Pendant Data Logger's* Light Sensor:

Calculate the Solid Angle for the Light Sensor:

Calculate the Luminous Flux of the Candle:

Calculate the Luminous Intensity of the Candle and the Percentage Error (Will Be Very Large):

Post Lab Questions:

1. According to its specifications, what is the nominal accuracy of the current measurement reported by the P4660 *Kill A Watt EZ* meter?
2. Identify each of the measured quantities used to estimate the number of moles of Carbon atoms in our sample of Graphite. What if each of these measured values is systematically too low by 10%? How would this impact the final estimate for the molar mass of Carbon?