Name		
Partner(s)		
Date		
Grade		
Category	**Max Points**	**Points Received**
On Time	5	
Printed Copy	5	
Lab Work	90	
Total	100	

Scales of the Universe

1. Introduction

Many students may feel that their mathematical knowledge will be a hindrance to their progress through introductory astronomy labs. This assignment will prepare students for the mathematical techniques that will be used this semester and in doing so students should be able to gain some insight into the size of the Earth and Sun, distances to nearby stars, distances within the Milky Way Galaxy and distances to other galaxies. Students will gain experience in using scientific notation, significant figures, choosing suitable units and the small angle formula.

You should read through this lab and attempt the pre-lab questions only **before attending**. Your TA will check your responses to the pre-lab questions.

2. Scientific Notation

Calculations in astronomy frequently involve very large or very small numbers, scientific notation is a convenient way of expressing these numbers that when used correctly should lead to fewer mistakes. For example, the average distance to the Sun (our nearest star) is 149597870690 meters. To simplify this you could say 150 thousand million meters but this can easily lead to confusion. Astronomers would rather write 1.50

x 10^{11} meters, which could be said out loud as "one point five oh times ten to the eleven".

Consider the number 320, 000 in scientific notation this will be written as 3.2 x 10^5. Scientific notation is often called "powers of ten" due to the " x 10", this means that the **base** is 10, changing the **exponent** (in this case 5) by 1 will change the number by a factor of ten, either to 32, 000 for an exponent of 4 or to 3, 200, 000 for an exponent of 6. The exponent must always be a whole number; it can be positive or negative but never a fraction.

Circle any of the following numbers which could be valid exponents:

2 8 0.2 15 -23 -1.5 1/2

In our example above 3.2 is the **coefficient**, for a number to be in correct scientific notation the coefficient must be greater than or equal to 1 but less than 10 or less than -1 but greater than -10.

Circle any of the following numbers which could be valid coefficients:

3.0 5.2 -3 0.8 15.7 -0.12

Two points to remember:

1. Numbers that are less than 1 will have a negative exponent, for example 0.0084 will be written in scientific notation as 8.4 x 10^{-3}.
2. You may find it useful to remember that the number in the exponent is the number of places that the decimal point will move.

Write the following numbers in scientific notation:

63,000

0.008

15,200,000

Write the following numbers in ordinary notation:

6.2 x 10^4

2.8 x 10^{-6}

6.0 x 10^2

One of the most problematic complications is that different calculators, computers, books have different ways of displaying scientific notation. Your calculator may use a button labeled “EE” or “EXP”. Try entering a number such as 3.2 x 10^5; may have to type 3.2 <EE> 5 or 3.2 <EXP> 5.

What does your calculator display?

Complete the following table:

Scientific notation	Ordinary notation	Coefficient	Base	exponent
3 x 10^8			10	
	23000		10	
6.677 x 10^{-11}				
	0.0014		10	
		1.6	10	-8

One of the conveniences of scientific notation is that it becomes relatively easy to multiple and divide large numbers. When you multiply numbers with scientific notation, multiply the coefficients together and add the exponents and when you divide numbers, divide the coefficients and subtract the exponents. In both cases the base remains the same, 10. Example:

(2 x 10^5) x (4 x 10^2) = 8 x 10^7 or 80,000,000

Note that we use parenthesis in these situations to avoid confusion about which operation to perform first. Using your calculator you would press

<2><EE><5><X><4><EE><2>.

Try the following examples:

(3 x 10^8) x (3 x 10^8) =

(4 x 10^3) x (2 x 10^2) =

(5 x 10^{-2}) x (4 x 10^{-3}) =

3. Significant Figures

Our next consideration is how much information is necessary, for our average Earth Sun distance we approximated 149, 597, 870, 690 to 1.50 x 10^{11}, we rounded up as well as using scientific notation. In this class we will typical use 3 significant figures and we will remember that if the first digit we “drop” is greater than or equal to 5 we will round up.

Write the following numbers using 3 significant figures:

12.415

3.142

8.00003

It is also important to remember when performing calculations that you should only use as many significant figures in your answer as the measurement with the least number of significant figures. For example 15.2 times 8. gives you 100 not 121.6. To be able to correctly answer 121.6 you would have calculated 15.20 times 8.000.

Try the following examples:

2.1 x 7. =

3.9 x 4.2 =

5.0 x 7.0 =

4. Measuring Distance

Here in the United States we use several different units of measurement for distance, for example, mile, yard, feet, inches. In the rest of the world the basic unit of length measurement is the meter. A meter is equal to 1.1 yards or 3.28 feet.

Because it is difficult for most people to visualize large numbers, we often compare large quantities to a quantity that we can comfortably visualize. For example during the peak of the 2008 flood approximately 40,000 cubic sq feet of water per second was flowing through the Coralville dam (including the emergency spillway flow), it is difficult to visualize that amount of water, however we can think about the amount of water contained in an Olympic sized swimming pool; typically 160 feet by 80 feet with a depth of 6 feet which gives us a total volume of 76,000 cubic feet. At this flow rate it would take less than 2 seconds to empty the UI Fieldhouse swimming pool (emptying 76,000 cubic feet at a rate of 40,000 cubic feet per second).

Now consider the **Earth’s radius**, which is approximately **6.37 x 10^6 meters** (6370 kilometers), let’s compare this value to a distance that we are more comfortable about visualizing. The tallest building in Iowa is 801 Grand (the Principle Building) in Des Moines, it has 45 floors and a height of 192 meters (630 feet). So the radius of the Earth is equivalent to 33,177 801 Grand’s (i.e. 6.37 x 10^6/192). Let’s make a second comparison; the distance between 801 Grand and the Old Capital Building is approximately 107 miles (172,000 meters). This comparison allows us to say that the Earth's radius is equivalent to 33 journeys between 801 Grand and the Old Capital (i.e. $6.37 \times 10^6/1.72 \times 10^5$).

The Moon has a radius of 1,740,000 meters. What is the Moon's radius in units of:

1. 801 Grand buildings?

2. The 801 Grand-Old Capital distance?

3. The Earth's radius?

The Sun has a radius of 1.39 x 109 meters. What is the Sun's radius in units of:

1. Grand buildings?

2. The 801 Grand-Old Capital distance?

3. The Earth's radius?

Now we will turn our attention to distances in the Universe. Van Allen Hall is approximately 80 meters in length. We are going to use the length of Van Allen Hall as a comparison for the Earth to Sun distance which is approximately 1.5×10^{11} m. We are going to plan a scale model, with the Sun at one end of Van Allen Hall and the Earth at the other. Each meter will represent 1.875×10^9 m (i.e. $1.5 \times 10^{11}/80$) of the Earth to Sun distance.

When we consider the Earth's radius; we find that on this scale it will be 0.34 cm (i.e. $6.37 \times 10^6/1.875 \times 10^9$).

Give an example of an object that has a radius of 0.34 cm:

What would the Sun's radius be on this scale?

5. Measuring Mass

We will be using kilograms and "Solar masses" to measure mass in this laboratory session. 1 Kilogram is equal to 2.2046 pounds. So an "average" person will have a mass of around 70 kg. The Earth has a mass of 5.97×10^{24} kg and the Sun has a mass of 2.00 x 10^{30} kg. This means that the Sun has a mass of about 330,000 Earth's.

In astronomy we tend to compare a star's mass to the Sun's mass, i.e. rather than say Rigel has a mass of 3.4 x 10^{31} kg we say it has a mass of 17 Solar Masses.

Give the following stars masses in solar mass units:

Vega 4.22 x 10^{30} kg

Betelgeuse 2.8 x 10^{31} kg

Arcturus 2.82 x 10^{30} kg

You are told that a typical galaxy has a mass of 5.00 x 10^{41} kg; if it was comprised of only solar mass stars, **how many stars would it contain?**

Which mass measurement system do you feel is most appropriate for astronomy and why?

6. Measuring Time

In our regular life time is measured using seconds, minutes, hours, days, weeks, months, years etc. In astronomy we will use either seconds or years to measure time. As we all know they are 60 minutes in an hour and 60 seconds in a minute. Therefore two hours is equivalent to 2 x 60 x 60 = 7,200 seconds. Defining a year is more difficult as there are several definitions for a complete orbit around the Sun. If we use a value of 365.2425 (the approximation our current calendar system uses) then, **how many seconds are in a year?**

Think of a third unit of time, explain for what type of situations your unit is preferable to seconds and years:

7. Measuring Temperature

In astronomy we will be using the Kelvin temperature scale; you will most probably have already met this in class. If you haven't met the Kelvin temperature scale please alert your TA. They will assist you in this section.

Complete the following table (hint see the formulae in section 9):

Fahrenheit	Celsius	Kelvin	Description
72°			Room temperature
	100°		Boiling point of Water
		0	Absolute zero
			Freezing point of water
350°			Warm oven
		5800K	Surface of the Sun

8. Angles in Astronomy

Astronomers use angles to measure distances in the sky; this is because the apparent separation of objects depends on their distance. For example if you are looking at a car next to you could estimate that the cars headlights are separated by about 1.1 meters. However, if that same car is now half a mile away the separation of the headlights is probably very small, maybe even too small for you to be able to see the two separate headlights. The distance between the headlights hasn't changed; the car's front end hasn't become smaller. Instead the angular separation of the headlights has changed; it has become smaller. A useful approximation is that one degree of arc is about the same size as a finger at arms length. When we need to measuring small angles we have to divide each degree into a smaller unit; we use minutes of arc. One minute of arc is equal to 1/60 of a degree of arc. 20/20 vision can resolve detail at a level of one minute of arc The full Moon is about 30 minutes of arc across, so it looks like we need an even smaller unit. So we use seconds of arc. Each second of arc is equal to 1/60 of a minute of arc **OR** 1/3600 of a degree of arc. 1 second of arc is a good angular resolution for an Earth based optical telescope.

We can use the following formula to convert from linear distance to angular size in seconds of arc if we know the distance:

Angular size = 206, 265 x linear size/distance

Note that the linear size and distance have to be in the same units. So for our car headlight example; a car located 50 meters away will have an angular size of 4540 seconds of arc (206, 265 x 1.1/50). 4540 seconds of arc is equal to 1 degree (3600 seconds of arc) with 940 seconds of arc left over. Or **1 degree** (3600 seconds of arc) **15 minutes** (15 x 60 seconds of arc) with **40 seconds** of arc left over If we assume that we have 20/20 (or at least corrective lenses equal to 20/20) vision we will be able to resolve that there are two headlights when the angular size is equal to one minute of arc (60 seconds of arc). So the car must be located (60 = 206,265 x 1.1/distance) at distance 3780 meters away. **Does this answer sound reasonable to you? (**Hint 1 mile equals 1609 meters)

Using the information in Section 4, calculate the angular size of the Sun as viewed from Earth:

9. Useful Formulae for 029:50 Students

Throughout this semester's labs and to complete your observational research you will be required to use some mathematical formula. You will find the formulae in the list below useful, you may still need to use other formulae during this semester, and you will meet them in your future labs.

Circle Circumference = $2 \pi r$ Area = πr^2

Sphere Area = $4 \pi r^2$ Volume = $4/3 \pi r^3$

Distance traveled by a body moving at a constant speed = **speed x time**

Small angle formula:
Angular size = 206, 265 x linear size/distance

Temperature conversions:
Temperature in Kelvin = Temperature in Celsius + 273.15
Temperature in Kelvin = (Temperature in Fahrenheit + 459.67) x 5/9
Temperature in Celsius = (Temperature in Fahrenheit -32) x 5/9

Frequently used prefixes
Kilo = 1, 000 = 10^3
milli = 0.001 = 10^{-3}
mirco = 0.000 001 = 10^{-6}
Mega = 1, 000, 000 = 10^6
nano = 0.000 000 001 = 10^{-9}

1 light year = 0.307 parsec 1 parsec = 3.26 light years

1 light year = 9.46×10^{15} meters 1 parsec = 3.09×10^{16} meters