Homework #4 Solutions

Answer parts 1 and 2 on a separate sheet of paper. You do NOT need to print this to hand it with your answers.

Part 1. Definitions

1. For each of the terms below, write two sentences. The first sentence should be a definition in your own words, and the second should be an explanation of how this concept is significant in Astronomy.

a) Electromagnetic Spectrum

The Electromagnetic Spectrum is the range of all possible wavelengths of light, from radio waves all the way to gamma rays. It is important in astronomy because astronomical objects can appear very different at different wavelengths, and each provides a piece of the puzzle explaining what is going on. For example, in the Sun Lab you saw that the sun appears very different at different wavelengths and that each tells you something different about what's going on in the sun.

b) Continuous/Emission/Absorption Spectrum

In all three cases here, we are talking about what we would see if we passed the light from a source through a prism or a diffraction grating, spreading it into its component wavelengths/colors, which is called generically a spectrum. BE CAREFUL though. This type of "spectrum" is different from the "Electromagnetic Spectrum", which is simply the range of all possible types (colors, frequencies, wavelengths, energies) of light!

A continuous spectrum is a rainbow of colors/wavelengths (including non-visible ones!) created by a hot, dense body like a star or a lightbulb filament. Objects that emit continuous spectra emit light at all wavelengths, but not necessarily in equal amounts. Continuous spectra are important because they tell us the temperature of an object based on where it gives off the most light (the "peak" wavelength).

An emission spectrum is given off by a hot low-density cloud of gas. Unlike a continuous spectrum, only certain very specific colors are emitted corresponding to the available energy transitions for electrons in the atoms that make up the gas. Each element has a unique set of available energy levels and therefore a unique set of colors (including non-visible ones!) that it can give off. This unique "fingerprint" allows us to tell which atoms are present in objects that emit emission spectra.

An absorption spectrum is a continuous spectrum with certain wavelengths "missing" from it, which appear as dark bands of missing colors among the rainbow. Like emission spectra, these dark bands correspond to available energy transitions in the atoms that make up a low-density gas. In order to create an absorption spectrum, you need a light source with a continuous spectrum to be behind a low-density cloud of gas. The light emitted by the hot, dense object that creates the continuous spectrum, which includes all wavelengths, passes through the cloud of gas, but only the colors that correspond exactly to transitions between energy levels in that gas can interact with the gas. The atoms of the gas absorb these specific colors, kicking their electrons up to higher energy levels and then almost immediately reemit them in a random direction. Because they were originally all traveling in a specific direction (straight from the light source to your eye), this means that even though the light eventually "escapes" the cloud of gas, less of it reaches your eye, resulting in missing colors in the spectrum. Like emission spectra, these dark bands tell us the composition of the gas that lies between the continuous source and us. This is especially important in studying the composition of stars, because although the photosphere where light escapes a star emits a continuous spectrum, that light then needs to pass through the outer layers of the star as well, giving it the fingerprint of whatever those layers are made of.

c) Random Walk

A "Random Walk" is the process by which a photon of light created in the nuclear fusion process at the core of the sun travels outward from the core to the photosphere, where it can travel freely. It cannot travel freely in the sun because of the extremely high densities. Once a photon is emitted, it will quickly interact with another atom in the sun and be reemitted in a random direction, making it's way very slowly outward over time. In class, we likened this to the process by which a drunkard walks away from a light pole if he takes a random 90 degree turn at each step. Although he makes progress away from the light pole, it is slow and follows a twisted path. In class we also used the equation describing the random walk (total distance traveled = mean free path (average distance photon travels before interacting with an atom) times the square root of the number of steps it takes) to calculate that it takes a photon created in a fusion reaction at the center of the sun approximately 50,000 years to escape from the photosphere. This is important because it tells us that the light we get from the sun is "old" – it tells us what was going on in the center of the sun 50,000 years ago. We use ***neutrinos,*** *which are nearly massless rarely interacting particles also created in fusion reactions at the center of the sun, when we want to know what's going on in the sun right now. This works because they interact with matter so rarely that they can fly right out of the sun immediately after they are created.*

d) Wavelength

*Wavelength is a property of a wave that measures how often it **repeats in space**. It is measured as the distance between two successive peaks or two successive troughs of a wave. To measure it, you have to imagine freezing the wave in time so that it's not traveling. Wavelength is important because it is indirectly proportional to the energy and frequency of a photon and, in terms of visible light, corresponds to the color of the light.*

e) Frequency
*Frequency is a property of a wave that measures how often it repeats **in time**. It is measured as the number of peaks or troughs passing a certain location in space per second. To measure it, you have to imagine standing still and allowing the wave to pass you. Frequency is important because it is directly proportional to the energy and indirectly proportional to the wavelength of a photon.*

2. Using what you know about wavelength, frequency and energy, write one paragraph explaining whether you think UV light from the sun or microwaves from your microwave are more likely to cause damage to the cells in your body.

UV light has very short wavelengths and therefore is very high frequency, high energy light. When skin cells absorb high energy light, that energy is dispersed into the body and can cause lots of damage. Radio waves, on the other hand, have very long wavelengths and are therefore a very low frequency, low energy form of light. They transfer very little energy when absorbed by the human body.

Part 2. Observing

Most of you did very well with this. When mistakes were made, it was generally probably that you were not standing close enough to the sign to tell the difference between what it was emitting and any ambient light. If you did this correctly, you should NOT have seen a continuous range of colors like when you look at ordinary lightbulbs, but a set of discrete colors corresponding to the spectral "fingerprint" of the gas in the tube. Based on which colors were present and which weren't, you could use the website to make an educated guess as to which element was in the tube.

Part 3. Math Skill #3: Math Skill #3: Scientific Notation

A number in scientific notation has the form:

$$A\times10^{B}$$

Where A is a number between 1 and 9.999999999 and can be either positive or negative, and B can be any whole number, positive or negative. If B is positive, it means that the number is very large. For example: 5×10^{9} *is 5 with 9 zeroes after it – 5,000,000,000, or 5 billion. If B is negative, on the other hand, it means that the number is very small. For example:* 3×10^{-6} *is a decimal point followed by 5 zeroes and then a 3 – .000003, or 3 millionths. In terms of easily turning the power in scientific notation into a number of zeroes, I like to think of this as 6 zeroes followed by a 3, with the decimal place between the first two zeroes. In other words, 0.000003.*

As you turn a number in scientific notation with a positive exponent into a number in ordinary notation, you take away a power of ten every time you move the decimal place. In other words, 2×10^{3} *is the same thing as* 20×10^{2} *is the same thing as* 200×10^{1} *is the same thing as 2000. Note that at each step you simply took away one power of ten and folded it into the A part of your number. This works because a power of ten is nothing more than a bunch of tens multiplied together, and in math you can group multiplied numbers however you want. So* 7×10^{5} *is* $7\times10\times10\times10\times10\times10$*, which I can group as* $(7\times10\times10)\times(10\times10\times10)$*, or* $700\text{x}10^{3}$ *or any other grouping that I can make and they will all be equivalent.*

This process is very similar for a number in scientific notation with a negative exponent except that every negative power of ten represents a division by 10. So 3×10^{-4} *is* $3\div10\div10\div10\div10$*. So every time you take away one of these powers of ten, you're folding one of those divisions into A. In other words,* 9×10^{-3} *is the same thing as* 0.9×10^{-2} *is the same thing as* 0.09×10^{-1} *is the same thing as 0.009.*

The other way to think about this (and to verify it) is that a positive exponent translates to moving the decimal place to the right, and negative exponents mean moving it to the left. Every time you move the decimal point past an empty space, you fill in a zero as a placeholder. For example, to write out -6.12×10^{4} *you need to move the decimal place 4 places to the right. The first two times you move it over, there are already numbers there to hold the place, but for the last two moves you need to fill in a zero, so written out this is -61,200.*

Now for how this is actually useful. Writing a number in Scientific Notation has several advantages, which is why it is used so frequently in science. First, by writing a number in scientific notation, ***the power of ten is built right in*** *so you can easily get a sense for how big or small the number is by using your powers of ten skills.*

Secondly, you will find that in many cases, especially dealing with very large or very small numbers, it is much easier to work with numbers in scientific notation than to *deal with their written out versions. It's easier to tell how big they are at a glance and easier on your hand to write them.*

Lastly, by writing a number in scientific notation, the number of significant digits is built right into your answer, which tells you how precisely you measured something. There are a number of complicated "rules" for significant digits, but they are made much simpler by scientific notation because ***if you bother to write it in scientific notation, then it is significant****. We will go over in more detail what "significant" means in the next math skill activity, but consider this statement in the back of your mind as you complete these exercises.*

Exercise 1: Rewrite the following numbers in scientific notation

10,000 = 1×10^{4}

100,000,000 = 1×10^{8}

0.00153 = 1.53×10^{-3}

42,386 = 4.2386×10^{4}

-0.00004 = -4×10^{-5}

900 = 9×10^{2}

0.023 = 2.3×10^{-2}

-8,599 = -8.599×10^{3}

A couple of things to note here:

1) ***You don't HAVE to have a decimal in your final answer, as in the first, second, fourth and fifth numbers in this list.***
2) ***A negative sign doesn't affect your moving it into scientific notation at all except that your coefficient will also have a negative sign in front of it.***

Exercise 2: Write the following numbers in scientific notation out in normal notation

1×10^{6} = 1,000,000

$6.45\text{x}10^{-4}$ = 0.000645

$3.14159\text{x}10^{16}$ = 31,415,900,000,000,000

$-4.238\text{X}10^{5}$ = -423,800

$2.001x10^{-5}$ = 0.00002001

$-9.2x10^{-10}$ = -0.00000000092

Exercise 3: "Fix" the following numbers by putting them into proper scientific notation. Remember that your answer will be mathematically equivalent to the number given, but in many cases easier to look at. If you have trouble, refer to the explanations on the first sheet of this Math Skill activity, or come see me at office hours.

30×10^2 = 30 is 3 x 10, so this is the same as (3 x 10) x 10^2 or **3 x 10^3**

1600×10^3 = 1600 is 1.6 x 1000, so this is the same as 1.6 x 10 x 10 x 10 x 10^3 or **1.6 x 10^6**

-125x10^4 = -125 is the same as -1.25 x 100, so this is the same as -1.25 x 10 x 10 x 10^4 or **-1.25 x 10^6**

0.002x10^{-2} = 0.002 is two thousandths, or 2 ÷ 1000, so this is the same as (2 ÷ 10 ÷ 10 ÷ 10) x 10^{-2} or **2 x 10^{-5}**

-0.00345x10^{-5} = -0.00345 is -3.45 thousandths, or -3.45 ÷ 1000, so this is the same as (-3.45 ÷ 10 ÷ 10 ÷ 10) x 10^{-5} or **-3.45 x 10^{-8}**

0.02x10^4 = 0.02 is two hundredths, or 2 ÷ 100, so this is the same as (2 ÷ 10 ÷ 10) x 10^4 or **2 x 10^2**

250 x 10^{-5} = 250 is 2.5 hundreds, or 2.5 x 100, so this is the same as (2.5 x 10 x 10) x 10^{-5} or **2.5 x 10^{-3}**

Note: Your intuition is your best weapon for deciding whether your exponent should be getting larger or smaller. Look at the "improper" scientific notation number. Is it's coefficient too big or too small? If it's too big, you need to encompass some of those extra powers of ten into the exponent, making it bigger. If it's too small, you need to pull some of the powers of ten out of the exponent, making it smaller.