U5

THE SCIENCE OF VISIBILITY

ELECTRONS AND THEIR INTERACTIONS WITH ELECTROMAGNETIC RADIATION

TEKS

Describe the mathematical relationships between energy, frequency, and wavelength of light using the electromagnetic spectrum.

LEARNING GOALS

Explain the electromagnetic spectrum using wavelength, frequency and energy.

Explain how electrons of elements are related to the electromagnetic spectrum.

Perform calculations of wavelength frequency and energy of light.

ESSENTIAL QUESTIONS

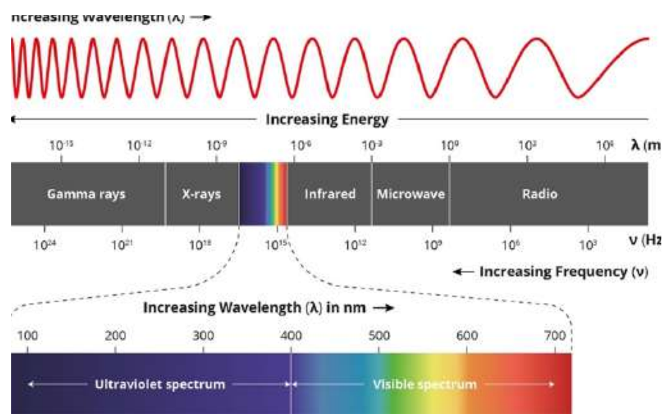
What information about the electromagnetic spectrum is important to understand?

How do electrons relate to the electromagnetic spectrum?

What is needed to perform calculations of frequency, wavelength and energy of light?

THE ELECTROMAGNETIC SPECTRUM

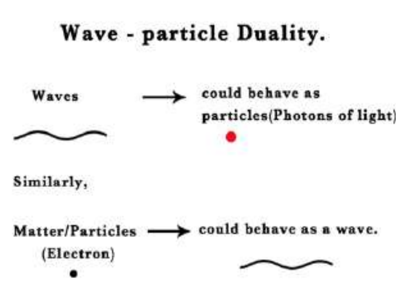
All light exists in a continuous spectrum ranging from gamma rays with tiny wavelengths less than 10 picometers (smaller than an atomic nuclei), to radio waves with wavelengths up to 100 kilometers. Humans can only detect a very narrow band of this spectrum called the visible spectrum. In this part of the spectrum wavelengths range from about 380 nanometers to about 750 nanometers. Each wavelength in the visible spectrum is associated with its very own color of light ranging from violet (smaller wavelengths) to red (longer wavelengths). See the diagram below:



WAVE-PARTICLE DUALITY OF THE ELECTROMAGNETIC SPECTRUM

Electromagnetic radiation, or light, exhibits what is called **wave-particle duality**, which means in some instances it behaves as we would expect a discrete particle of energy to behave and in others it behaves as a wave; having the ability to be **refracted** (bent) and **diffracted** (spread out after passing through a narrow opening). Most observable phenomena of light can be attributed to its wave-like properties.

When light behaves as a particle, it is behaving like discrete "packets" of energy that we call **photons**. An example of a situation where light seems to behave as a particle can be observed in the **photoelectric effect**, in this instance, light is shined on a metal plate in a vacuum and electrons are ejected from the surface of the metal. Because we know that electrons can only absorb or release very specific amounts of energy, scientists explain that the photons striking the plate are completely absorbed by the electrons in the metal atoms, and those electrons are excited to such a degree that they are ejected from the metal atoms.

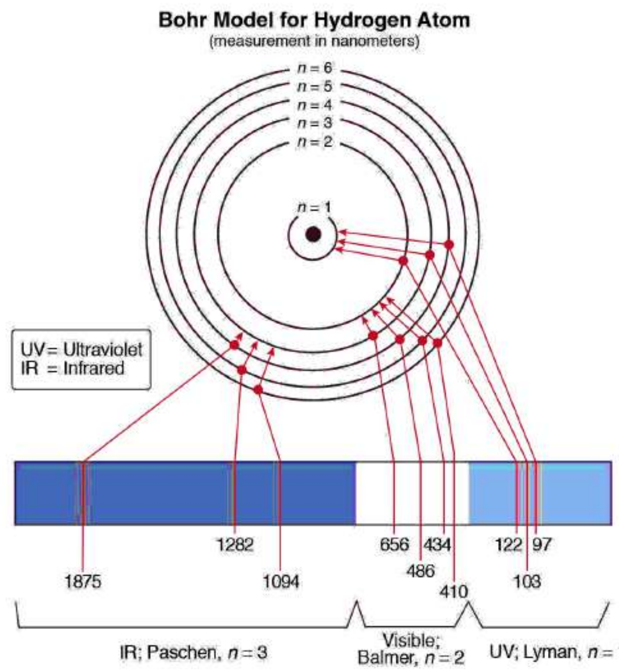


ELECTRON TRANSITIONS AND EMISSION SPECTRUM

What do the electrons in atoms have to do with light??

Electrons, like photons, exhibit wave-particle duality! In fact, electrons absorb and emit photons of light all the time! It is the photons of light that are continually being absorbed and emitted from the electrons of atoms (and molecules) that our eyes detect allowing us to see objects.

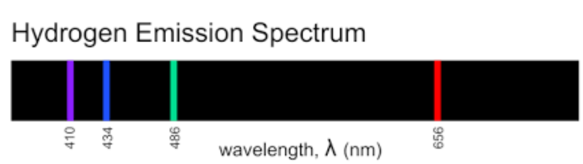
When an electron absorbs a photon, it becomes **excited** and undergoes a transition from one "allowed" energy state to a higher "allowed" energy state in its atom. In order for an electron to be able to transition to a higher energy state, the photon it absorbs must contain an amount of energy that is exactly equal to the energy difference between the initial and final energy states or the photon will not be absorbed and no transition will occur. However, it is possible for an electron in the outermost energy level to gain enough energy to be ejected, thus, ionizing it.



Electrons that are in excited states will eventually emit a photon of light in order to "relax" back down to their **ground state** which is the lowest energy level a particular electron can occupy in that atom. The transition of an electron back to its ground state can occur in a single step, releasing a single photon, or in multiple steps, releasing multiple photons. In either case, the energy of the photon or the sum of the energies of each photon (for a multi-step relaxation) that are released must be equal to the total energy that was absorbed between the ground state and the highest excited state.

The photons emitted by electrons as they transition back down to lower energy states can have wavelengths anywhere along the electromagnetic spectrum. For hydrogen, all possible transitions that occur with electrons having a ground state in the first energy level n=1 are called Lyman series transitions and emit photons in the Ultraviolet range of the EMS. All possible transitions that occur with electrons having a ground state in the second energy level, n=2, are called Balmer series transitions and emit photons in the visible range and all transitions that occur with electrons having a ground state in the third energy level, n=3, are called Paschen series transitions and emit photons in the Infrared range of the EMS. Both the Lyman and Paschen series transitions are invisible to us.

Atoms of each element have their own unique set of energy states (aka energy levels), the energies associated with each energy state are dictated by the number of protons or the amount of positive charge in the nucleus. This allows us to use the light emitted to identify the presence of different elements, it is just like a "fingerprint" for elements and molecules! We call the collective wavelengths of light that are emitted by an element's atoms an **emission spectrum**. We can use the visible range to identify every element on the periodic table.



Use this link to view the Balmer series transitions for hydrogen in a simulation.

ACTIVITY #1: IDENTIFYING ELEMENTS WITH SPECTRAL DATA

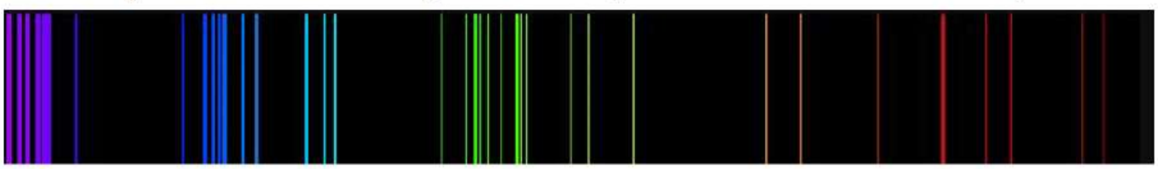
Our sun emits a continuous spectrum of light mostly as a result of its ongoing chemistry and high temperatures but using an instrument with fine spectral resolution it is possible to determine the true composition of a star. A team of astrophysicists have gathered the emission spectrum of various stars. Their findings are given below. Use the spectral data to determine the composition of the star. **Each star is only made up of one element and all elements are smaller than Krypton (atomic #36). A table of known spectra are found here: tinyurl.com/atomicspectra192

Fill in the elemental composition for each star in the space provided above the emission spectrum.

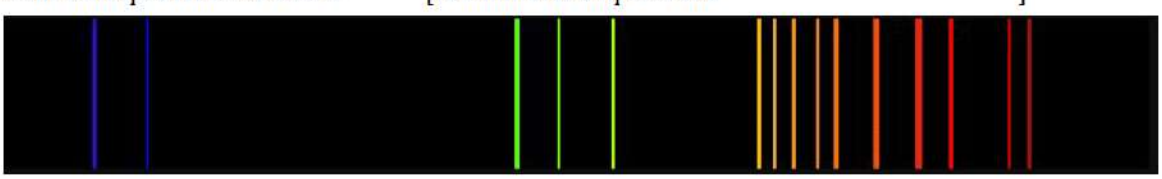
Emission spectrum of Star A [Elemental composition:]

Emission spectrum of Star B [Elemental composition:]

Emission spectrum of Star C [Elemental composition:]

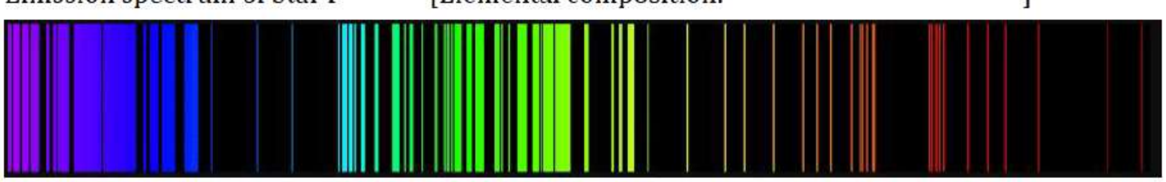


Emission spectrum of Star D [Elemental composition:]



Emission spectrum of Star E [Elemental composition:]

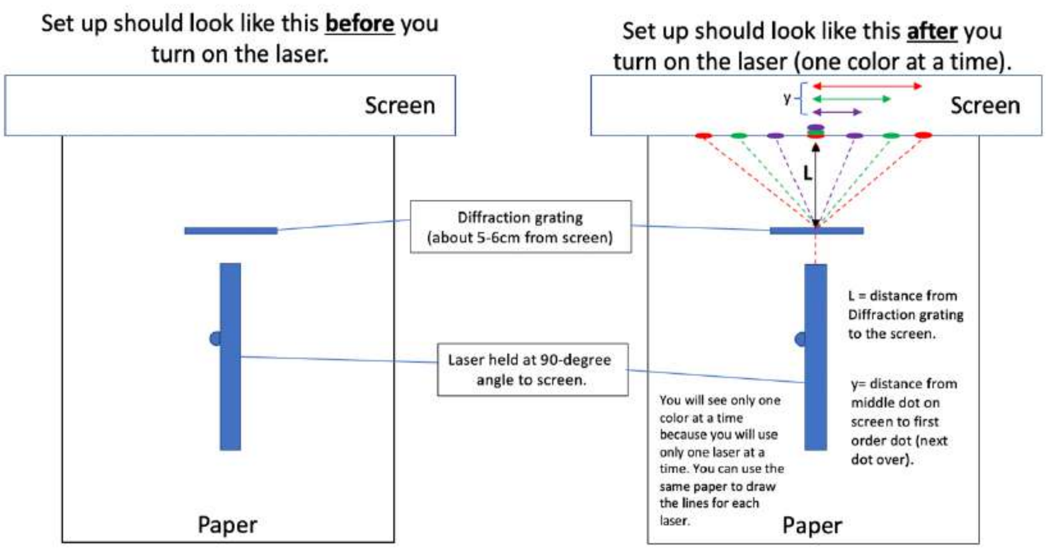
Emission spectrum of Star F [Elemental composition:]



ACTIVITY #2: MEASURING WAVELENGTH

For this activity you will measure the wavelength of three different lasers (Red, green and violet) then you will calculate the amount of energy and the frequency for each. Follow the directions below in order to set up.

1. Set up your screen and a plain white sheet of paper as shown below, make sure to mark the location of your screen and the diffraction grating on your paper.



2. Obtain one laser from your teacher at a time. (Warning! Laser light can be very dangerous!! NEVER shine the lasers in anyone's eyes, NEVER shine the laser on a reflective surface including glass, USE ONLY AS INSTRUCTED). Do not turn the laser on until you are ready to make your measurements.
3. Once laser is turned on, quickly (without directly staring at the light) mark a dot on the paper using a pencil, directly below where each laser dot shows on the screen. Then turn the laser off.
4. Using your pencil, trace a line directly from the line where the diffraction grating was to the middle mark on your paper. Trace a second line from the same spot on the diffraction grating line to the second mark on your paper (see the dotted lines in the diagram above). Label these lines with the color of the laser used.
5. Repeat steps 2-5 until you have done all three lasers, each laser can be done with the same sheet of paper.
6. Measure the line L and the distance y, for each laser and record those measurements in the table below.

Light Source:	Distance from Diffraction Grating to the screen (L) in cm.	Distance from Middle light spot to the first dot to the right or left (y) in cm.	Measured Wavelength of light in nanometers (nm)	Wavelength on label
Red Laser				
Green Laser				
Violet Laser				

7. Use the calculator that Mrs. Bufford made for you on itslearning to calculate the wavelength of light for each laser. Record this in the table above. The formula used by this calculator is the one to

$$\lambda = d\left(\frac{y}{\sqrt{L^2 + y^2}}\right)$$

the right. You will NOT need to know how to use this formula for the test but you WILL need to know the three on the next page.

ACTIVITY #3: ENERGY, WAVELENGTH AND FREQUENCY OF LIGHT CALCULATIONS

Using the equations below, calculate the energy and frequency for the laser light you determined the wavelength for in Activity 3.

$$\mathbf{E = hv} \qquad \mathbf{v} = \frac{c}{} \qquad E = \frac{hc}{}$$

E = energy in Joules (J)
h = Planck's constant, 6.626×10^{-34} J•s
v = frequency (Hz or s^{-1})
c = the speed of light in a vacuum, 3.00×10^{8} m/s
λ = wavelength in meters (m)

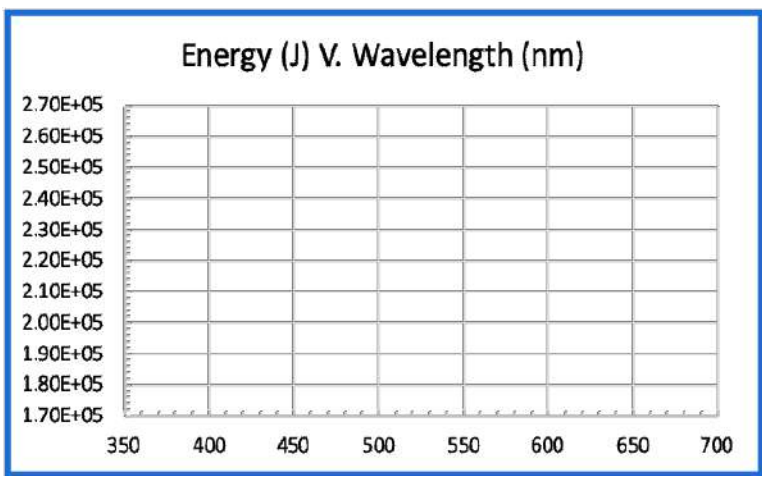
Hint: **On your calculator use the $\boxed{\text{EE}}$ button for exponents. Remember to use the $\boxed{+/-}$ key for negative exponents, not the subtraction key!**

Light Source:	**Measured Wavelength of light in nanometers (nm)**	**Energy of light in Joules (J)**	**Frequency of light in Hertz (Hz or 1/sec)**
Red Laser		**1.**	**2.**
Green Laser		**3.**	**4.**
Violet Laser		**5.**	**6.**

USE THE SPACE BELOW FOR YOUR CALCULATIONS… SHOW YOUR WORK!! DETERMINE SIGNIFICANT FIGURES USING THE RULES FOR MULTIPLYING AND DIVIDING!!

ACTIVITY #4: PLOTTING THE DATA

Use the graphs provided on this page to plot the data you calculated for all three lasers in activity #3. Then Describe the relationship between each variable and answer the questions. (You should plot the data for all three lasers on each graph below).



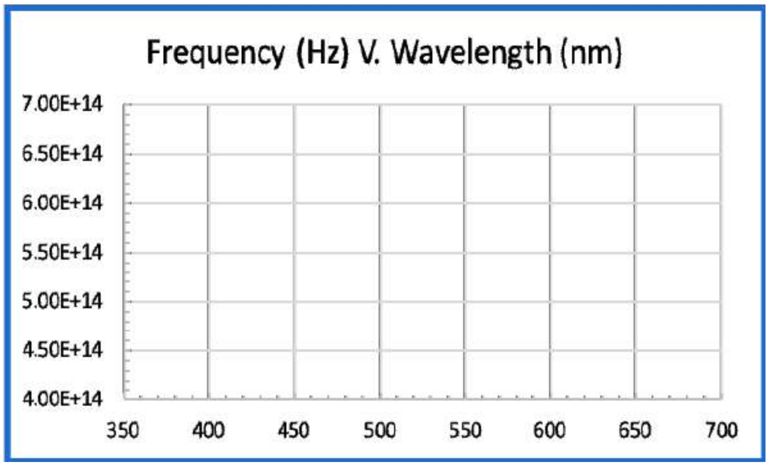
The relationship between energy and wavelength is:

____________________, this means that as energy

increases, wavelength ______________________.

Does this confirm what you thought in Activity #2?

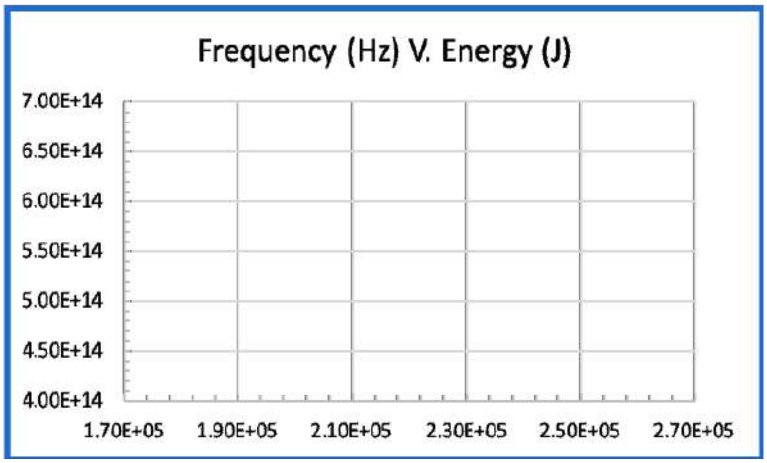
Write the equation that shows this relationship:



The relationship between frequency and wavelength is: ________________________, this means that as frequency increases, the amount of energy ________________________.

Does this confirm what you thought in Activity #2?

Write the equation that shows this relationship:



The relationship between frequency and energy is: ________________________, this means that at the frequency increases, wavelength

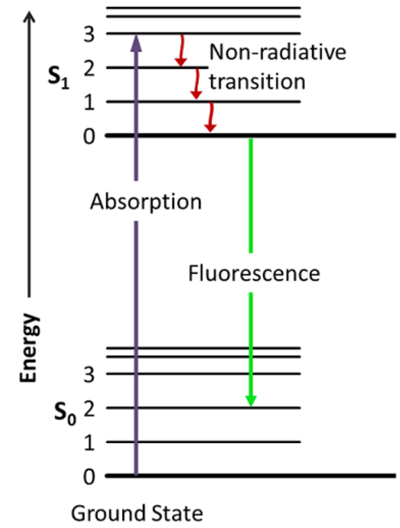
_____________________.

Does this confirm what you thought in Activity #2?

Write the equation that shows this relationship:

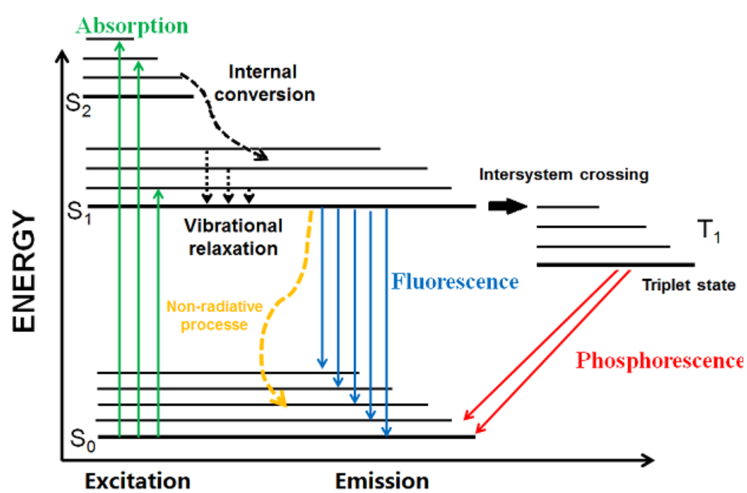
EXTENSION (BONUS KNOWLEDGE & PLAY): PHOTOLUMINESCENCE

Photoluminescence is the emission of light from any form of matter after the absorption of photons. Two types of photoluminescence that we find particularly entertaining or useful are fluorescence and phosphorescence. The main difference between these two phenomena is the amount of time it takes for the emission of the absorbed energy to occur. With fluorescence the emission of photons ceases when the light source stops shining on the molecules, in phosphorescence, the emission is delayed or slowed down and can continue to occur after the light source has been removed.



FLUORESENCE occurs when the wavelength of light emitted by a molecule is longer (less energetic) than the wavelength of light it initially absorbed. This can occur when a molecule loses kinetic (or vibrational) energy as it collides with another molecule causing non-radiative transitions to occur. The energy that is lost as kinetic energy in the collision, is not large enough to bring the atom all the way back down to its ground state, so the atom emits a photon equal to the new energy difference between its lowest-energy excited state and its ground state. Since some energy was lost as kinetic energy, the energy associated with the photon emitted will be less than the original amount of energy the atom absorbed and thus have a longer wavelength. Examples of this can be seen when substances absorb light from the ultraviolet or x-ray regions (having higher energy and shorter wavelength than the visible spectrum) and emit photons in the visible spectrum. Because fluorescence always occurs as a transition from the lowest-energy excited state to the ground state, the emission spectrum is always the same, regardless of the wavelength of light used to excite the molecule.

PHOSPHORESCENCE is the quality of seeming to glow in the dark. This occurs when photons of light are absorbed by large molecules of phosphorescent substances and slowly relax back down to their ground states. The electrons fall back to their ground state at a very slow rate because they are involved in "forbidden" energy state transitions (triplet state in quantum mechanics). You can think of these electrons as being temporarily trapped or stored in the higher "forbidden" energy states and when they finally fall back to their ground state, they emit a photon of light equal to the distance from their excited triplet state, to the ground state. Because these transitions are not kinetically favored, they take much longer to occur in some substances this can take minutes to hours to complete emission.



More…

CHEMILUMINESCENCE - This differs from Fluorescence and phosphorescence because rather than being initiated by the absorption of a photon, the emissions are powered by energy differences that occur as a result of a chemical reaction. Similar to how some reactions give off thermal (or Infrared) radiation, other reactions may give of energy in the form of light!

PHOTOCHROMISM - Sometimes introducing certain substances to electromagnetic radiation with certain wavelengths can cause a molecule to change shape or rotate around a chemical bond. When this happens, it is possible for the spectral output of the molecule to change meaning that before you added energy the shape the molecule had emitted light of a certain wavelength and after you added the light, the molecule absorbed those photons causing it to change shape which in turn causes it to emits light at a different wavelength making it appear a different color!

INFRARED RADIATION

This is here so you can have an opportunity to use the infrared or thermal cameras to see thermal emissions (infrared radiation)! Try the following things with the infrared cameras.

THERMOCHROMISM - Here thermal energy (infrared radiation) is used to change the color of light emitted by a thermochromic substance. There are two ways this can be accomplished. **The first** is through the use of liquid crystals, these are substances that behave like solids in some ways and liquids in others and their molecules are arranged in a parallel orientation to one another forming crystal like structure in a fluid. When heat energy (infrared radiation) is added, increasing the temperature, these molecules move farther apart from one another changing how light is diffracted through the substance, thus changing the wavelength (or color) of light emitted! An example of where you would see the results of this type of material in everyday use is in LCD screens on your computer or television! **The second** method that uses thermal energy to change the color of light emitted uses something called leucodyes, these are organic (carbon based) molecules that experience a temporary change in their molecular structure (they change shape, similar to Photochromism) that causes them to emit light at different wavelengths. An example of this type of material would be Mrs. Bufford's Dr Who mug… when she adds hot water to it the Tardis appears!

Expose each substance to the following sources of EM radiation, *make observations and use the terms* *Instantaneous emission, lingering emission, color change or X for no emission/change.* **Be sure to view these under the thermal camera too.**

Test Substance ⇒ / **Tests ⇓**	**Substance A:**	**Substance B:**	**Substance C:**	**Substance D:**	**Substance E:**	**Substance F:**
LED						
Incandescent						
UV						
Infrared (Human Touch)						
Use the best term to describe this substance: *Fluorescent, Phosphorescent, Chemiluminescent, Photochromic, Thermochromic Infrared emission.*						

WARNING!! DO NOT SHINE ANY OF THE LIGHTS AT ANYONES FACE OR AT ANY REFLECTIVE SURFACE!

Take a few minutes to play with the infrared Cameras! You can see your body emitting infrared radiation… put your hand on the desk for a few seconds and them pick pit up and look at the desk with the thermal camera ☺