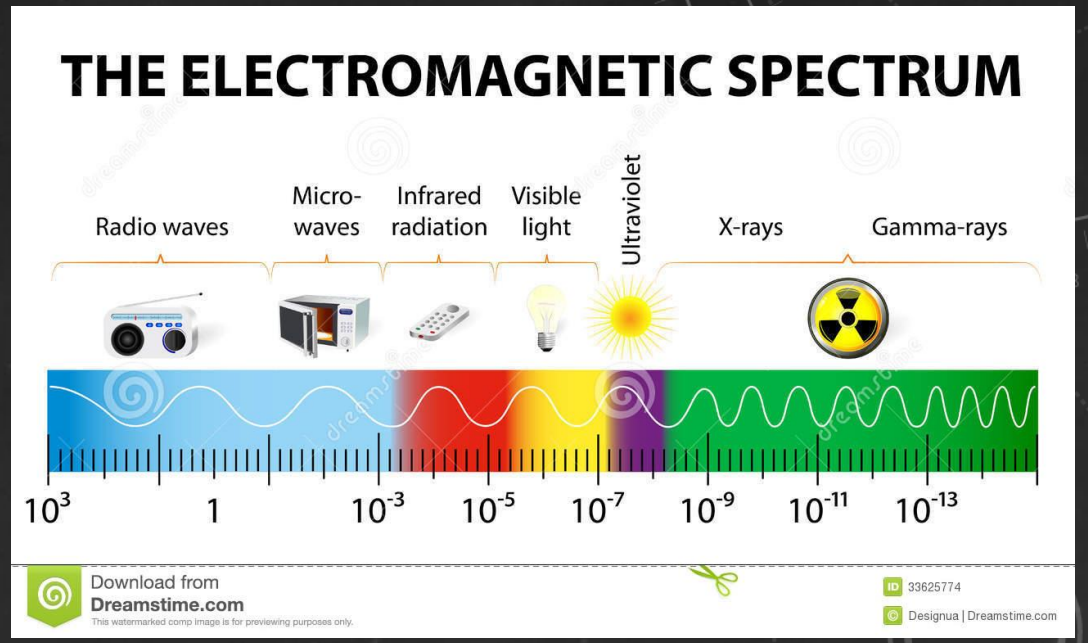
# THE ELECTRO-MAGNETIC SPECTRUM

PES 1000 – PHYSICS IN EVERYDAY LIFE

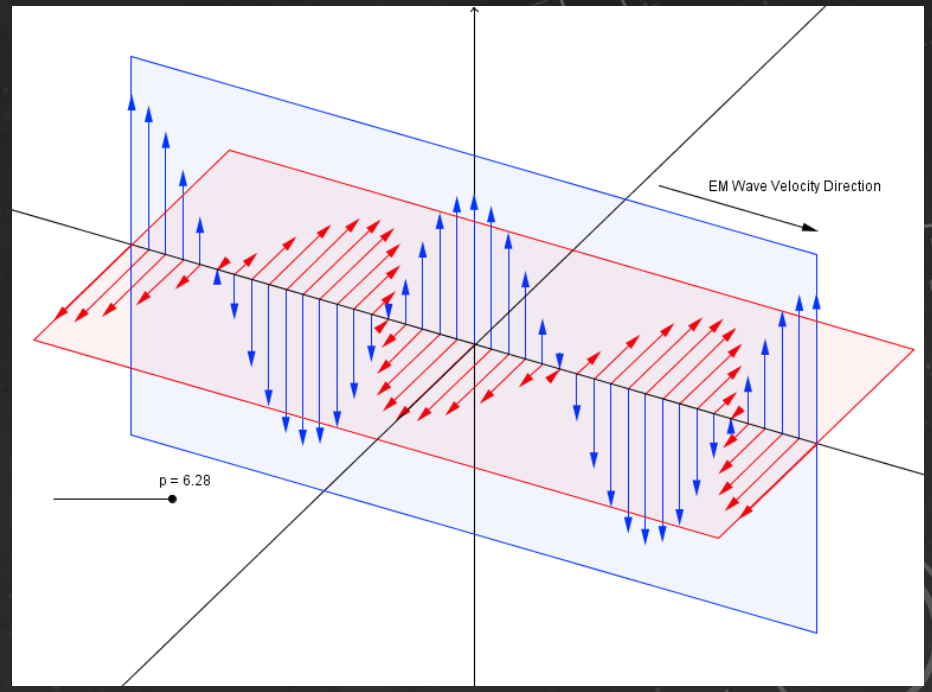
# WHAT IS LIGHT?

- We use the term ‘light’ to refer to many different types of radiating phenomena, including gamma rays, x-rays, ultra-violet rays, infra-red, radio waves, in addition to visible light.
  - As with mechanical waves, light is a transfer of energy from a source.
  - Unlike mechanical waves, no physical medium is required.

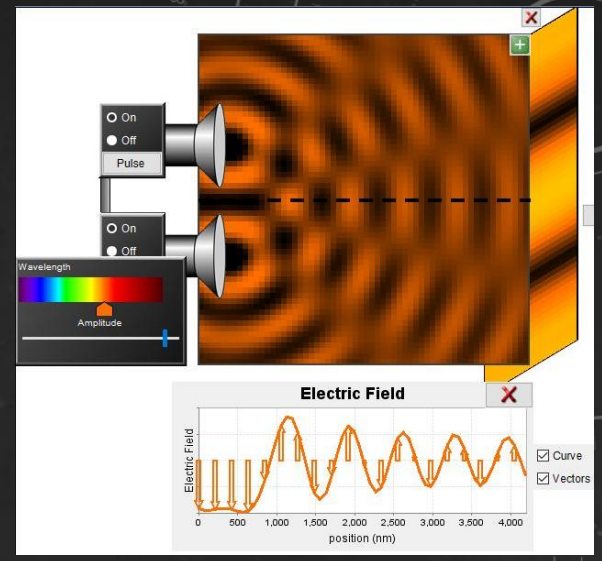


# WHAT IS LIGHT?

- Analogously to air pressure for sound waves, space is filled with an electric field and a magnetic field at some baseline strength.
  - The light wave is a disturbance in these fields that ‘ripples’ away from the source.
  - The fields oscillate together, but the electric field direction is at right angles to the magnetic field.

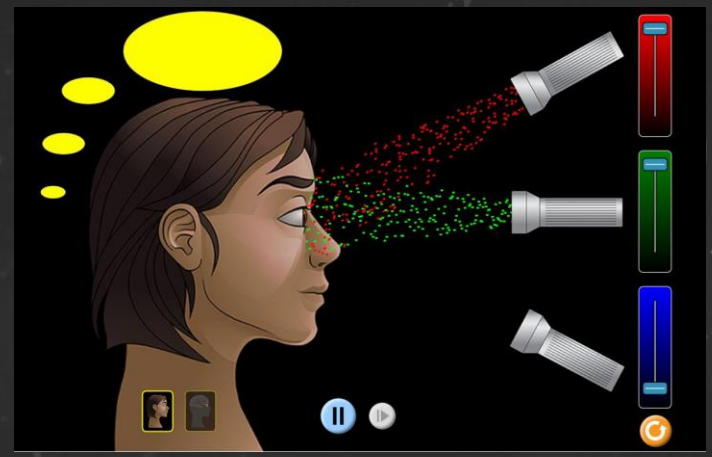


# LIGHT: WAVE OR PARTICLE?



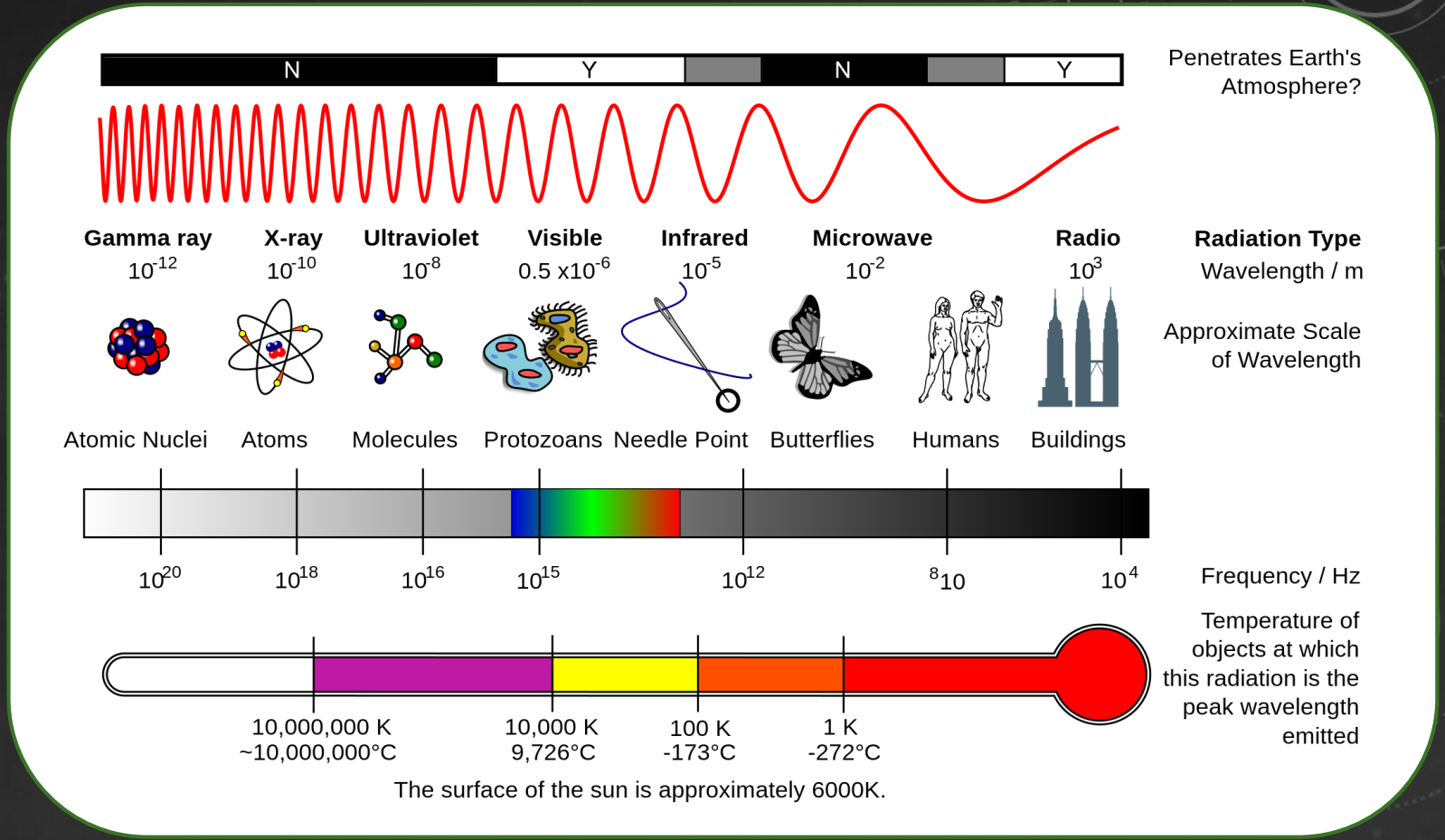

- We have characterized light as a wave, so far, but we will also be referring to particles of light, called 'photons'. So which is correct?
- Answer: Both. This is called 'wave-particle duality'. Light has wave-like properties and particle-like properties, depending on how it is measured.

- Wave properties
  - Light has a wavelength and a frequency
  - Light waves can interfere with each other constructively and destructively
- Particle (photon) properties
  - A beam of light can be broken down into a stream of finite, localized bits of energy.
  - Each photon contains a certain amount (a quantum) of energy.
- Common properties
  - Speed of light: $c=3 \times 10^8$ m/s (in a vacuum)
  - Massless



# THE ELECTRO-MAGNETIC (EM) SPECTRUM

- Light can be characterized by either its frequency or its wavelength, because these two quantities are related by the constant speed of light. ($c = f*\lambda$)
- As frequency goes up, wavelength decreases.
- We give names to regions of the spectrum. The boundaries of these regions are arbitrary.



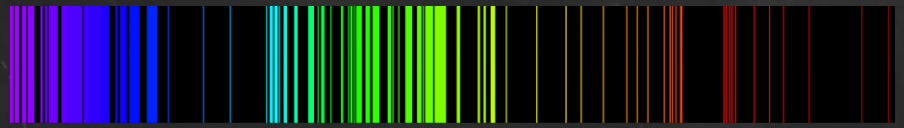
# INTERACTION OF LIGHT AND MATTER

- Recall our simplified model of an atom
  - Electron shells (or energy levels) encircle a positively charged nucleus
  - Electrons obey the general rules that they try to drop as low as possible, they are limited to two electrons per level, and they cannot change levels unless they absorb or release an amount of energy exactly equal to the energy difference between levels.
- How can an electron be made to jump up to an available level?
  - It can be elevated by collisions with other atoms (heat).
  - It can absorb energy from a photon with exactly the right amount of energy.
- When an electron drops to an available level, it will release that amount of energy in the form of a photon.

# LIGHT INTERACTING WITH AN ATOM OR MOLECULE

- Only a photon with exactly the right energy can be absorbed or emitted.
- Every atom/molecule has a unique set of electron shells (energy levels), and so a unique set of colors (wavelengths, frequencies) it can either emit or absorb.
  - This is how we can tell what a star is made of even though it is light years away.
- An emission spectrum is black (no light) with colored lines (emission lines).
- An absorption spectrum is all colors (from the white light) with black lines (absorption lines) where the atoms have scattered those colors.
  - The emission spectrum of a molecule is the reverse of its absorption spectrum.

Emission spectrum



Absorption spectrum

# GENERATING AN ELECTRO-MAGNETIC WAVE

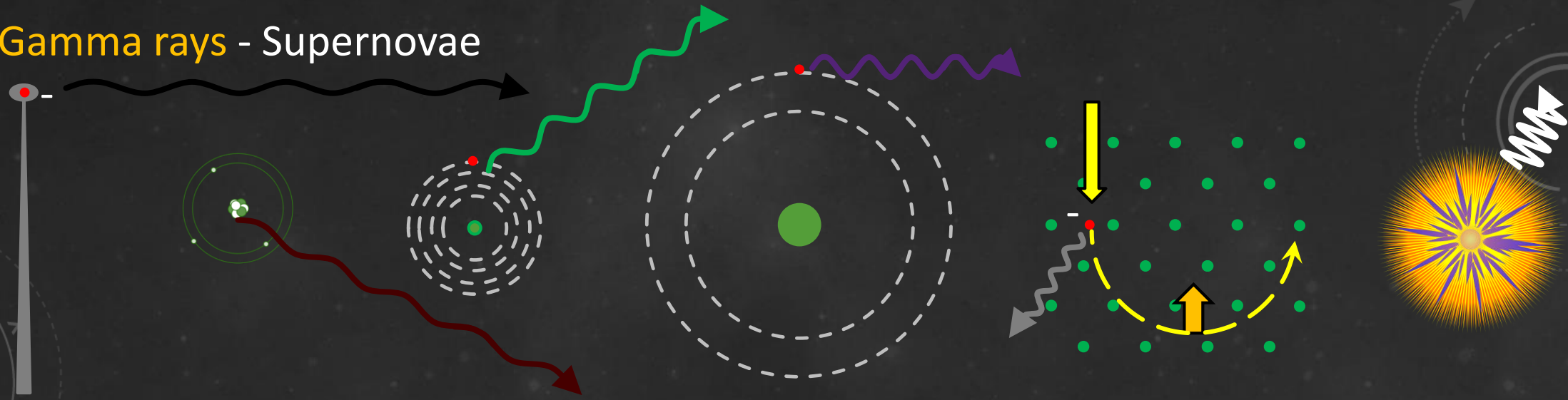
- A stationary charge generates a static electric field.

- A charge moving at constant speed also generates a constant magnetic field.


- An accelerating charge also emits an electro-magnetic wave as it gains or sheds energy.

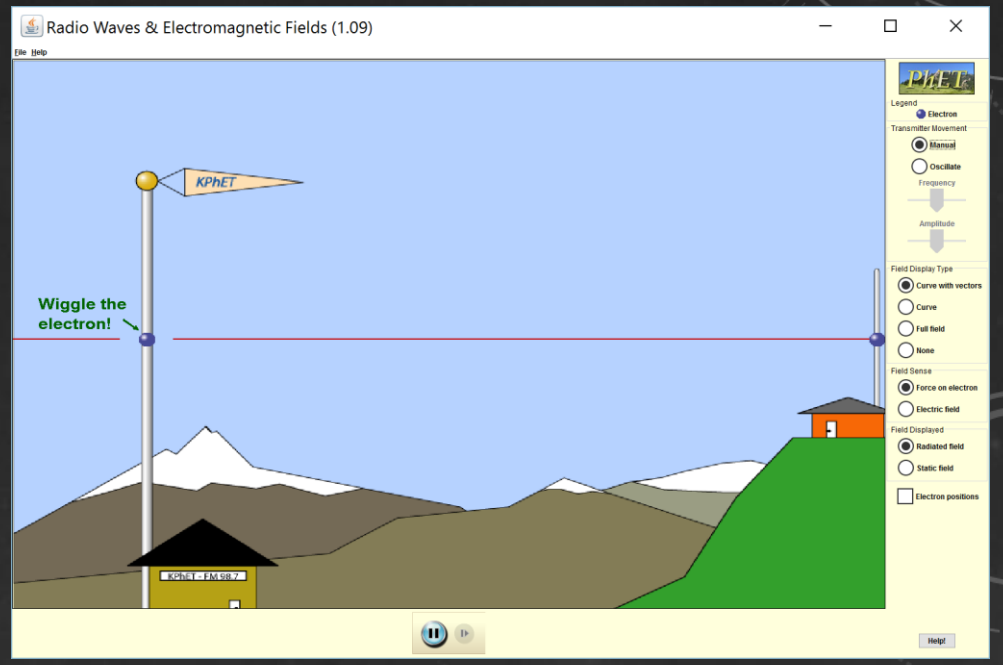
# SOURCES OF EM WAVES

- Radio: electrons moving up and down an antenna
- Infra-red – moving atoms/molecules
- Visible light – electrons jumping between shells (far from nucleus)
- Ultra-violet – electrons jumping between shells (near nucleus)
- X-rays – Electrons hitting a lead target or cyclotron motion
- Gamma rays - Supernovae



# SIMULATION – RADIO WAVES

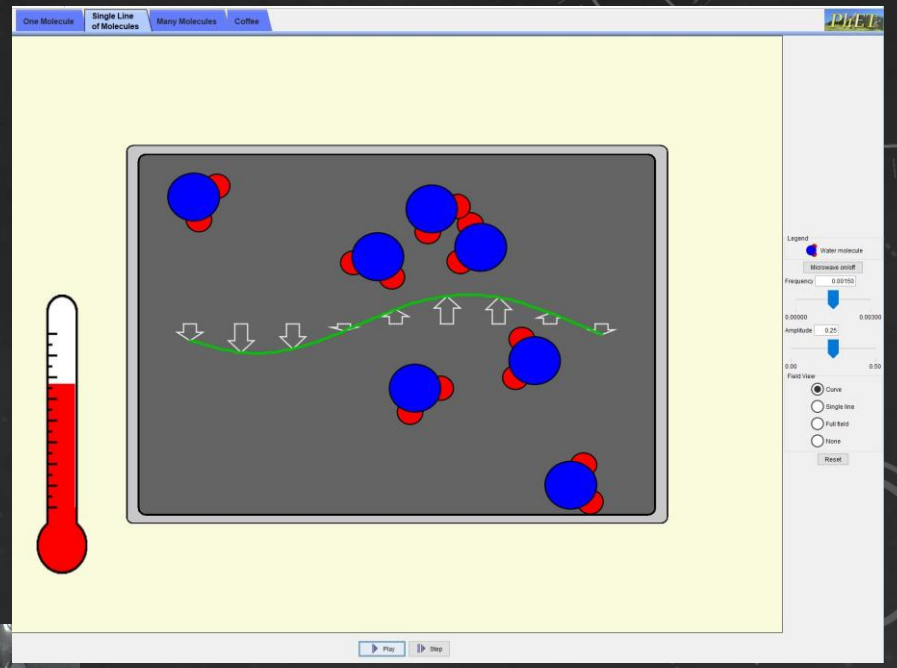
- Link to simulation: https://phet.colorado.edu/en/simulation/legacy/radio-waves
- Things to do:
  - Select the ‘Oscillate’ button under ‘Transmitter Movement’ on the right.
  - Watch the electrons in the transmitter release radio waves as the accelerate and decelerate.
  - Watch the electrons in the receiving antenna oscillate in response to the radio wave.

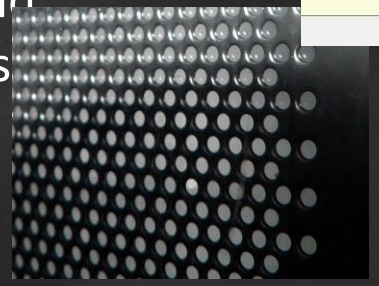


# SIMULATION – MICROWAVES

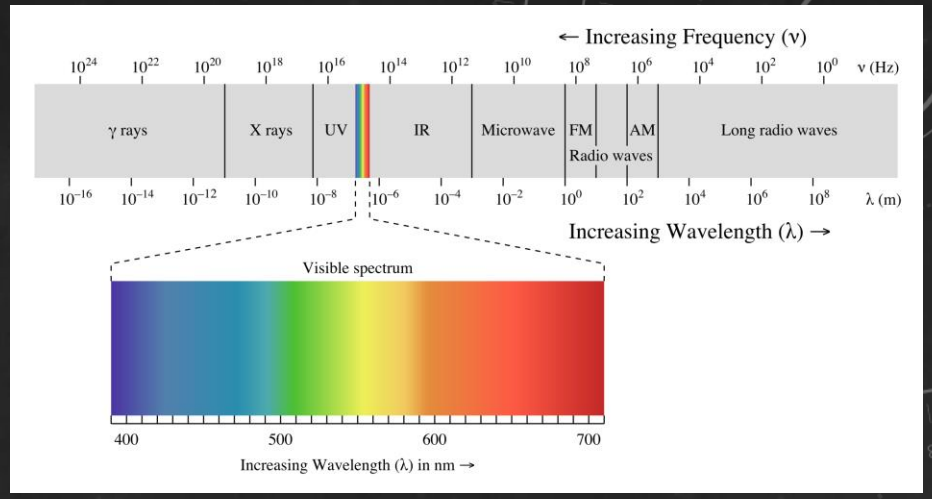
- Link to simulation: https://phet.colorado.edu/en/simulation/legacy/microwaves

- Things to do:
  - Select the 'Single Line of Molecules' tab.
  - Watch as the oscillating electric field causes the stationary water molecules to move and spin, increasing their temperature.
  - The metal interior causes the microwaves to bounce around in the chamber.
  - Microwaves have a frequency of 2.45 GHz and a wavelength of about 12 cm. They can't pass through the holes in the door screen.



# CONCLUSION




- Light consists of many different wavelengths in the electro-magnetic spectrum.
  - We give names to some regions: visible light, x-rays, ultra-violet, radio, infra-red.
  - Wavelength and frequency are related by the speed of light.
- Light has both wave-like and particle-like properties.
- EM radiation is emitted when charge accelerates.
- A unique emission/absorption spectrum is associated with a particular atom or molecule, based on its energy levels.
- Different wavelengths/frequencies of light are generated by different phenomena.

# IMAGE ATTRIBUTION

- Prism: https://commons.wikimedia.org/wiki/File:EM_Spectrum_Properties_reflected.svg
- Emission spectrum: https://commons.wikimedia.org/wiki/File:EM_spectrum.svg
- EM spectrum with sources: https://commons.wikimedia.org/wiki/File:Emission_spectrum-Fe.svg
- Emission spectrum: https://commons.wikimedia.org/wiki/File:Blackbody_Spectrum.PNG
- Absorption spectrum: https://commons.wikimedia.org/wiki/File:Absorption_spectrum_of_few_elements.PNG
- EM sources: https://commons.wikimedia.org/wiki/File:Electromagnetic-spectrum-vector-diagram-different-types-radiation-their-wavelengths-order-increasing-frequency-33625774.jpg
- Atom: https://openclipart.org/detail/219360/lithium-atom-in-bohr-model