INST 2403 Activity

Electromagnetic Waves

Light is an electromagnetic wave. As such, it shares properties with familiar types of waves such as the wave on a vibrating string, sound in air and waves on water. The main equation states that the speed of a wave is the product of its wavelength and its frequency: $c = \lambda f$. The speed of light is c = 300,000 km/s.

Part I: Fundamental relations

1. Calculate the frequency of red light of wavelength 600 nm. If you use scientific notation ($c = 3 \times 10^8$ m/s, $\lambda = 6 \times 10^{7}$ m) you should be able to do this without a calculator.

   $1\ Hz = 1\ \frac{1}{s}$

   $$f = \frac{c}{\lambda} = \frac{3 \cdot 10^8 \frac{m}{s}}{6 \cdot 10^{-7} m} = 0.5 \times 10^{8+7} \frac{1}{s} = 5 \cdot 10^{14}\ \underline{\underline{Hz}}$$

2. How would the frequency change if the wavelength would be half as long?

   $\lambda \to \frac{1}{2}\lambda \Rightarrow f \to 2f$, so $(\frac{1}{2}\lambda)(2f) = c$

3. How would it change if the wavelength would be twice a long?

   $\lambda \to 2\lambda \Rightarrow f \to \frac{1}{2} f$ so $(2\lambda)(\frac{1}{2}f) = c$

4. Rank the speeds of the electromagnetic waves in 1-3 which have different wavelengths, and therefore different frequencies.

   They all have the same speed (c).

5. Formulate a rule (in words) that states the relationship between frequency and wavelength of an electromagnetic wave.

   The higher f, the shorter λ. They need to produce the same constant speed $c = 3 \cdot 10^8 \frac{m}{s}$.

6. Compare red light with a radio wave. Which one, if any, has the higher frequency, the longer wavelength, higher speed, and higher energy?

   Radio wave: lower f, longer λ, same speed, lower energy

   Vis. Light: higher f, shorter λ, same speed, higher energy

Part II: Brightness and distance

The brightness of an object depends on how much light it sends out (luminosity L) and the distance between the object or light source and the observer (radial distance r). Brightness is a measure of how bright, say, a star *appears* in the sky, while luminosity is a measure of how much light or energy a source sends out – regardless of its distance. Luminosity is measures in Watts (1W = 1 Joule/sec), while brightness is measured in Watts per square meter (W/m^2). Astronomers often use the so-called **magnitude scale** to measure brightnesses of stars, in which a brighter star has a smaller magnitude number. The fundamental relation between brightness, luminosity and distance is

$$B = L / (4\pi r^2)$$

7. You are in a big but dark room and view a 400 W lightbulb from 10 m. At this point, which of the following do you know: brightness, luminosity, distance.
   → Know all three ✓ ✓ ✓
8. A second lightbulb is placed next to 400 W lightbulb. It appears to be four times dimmer than the 400W lightbulb. What can you conclude?
   Its luminosity is 4x lower → It is a 100W light bulb
9. A third lightbulb is placed somewhere in the room. It also appears four times dimmer than the 400W lightbulb. What can you say about its distance and luminosity?
   Nothing. We do not know d, so we cannot say anything about L.
10. List two possible luminosity/distance combinations that would "save the appearances", i.e. reproduce the brightness pattern described in 9.
    100W & 10m or 5m & 25W or 1m & 1W

Part III: Doppler Effect

11. Light is sent out from a moving source. Two wave fronts looking like circles have been drawn. Draw in the other two wave fronts (centered on the moving object) as the source is moving towards an observer. Is the wavelength perceived by the observer shorter or longer than the one sent out by the light source? Explain!