Portland State University
General Physics Workshop
Problem Set 3 **Doppler Effect and Electromagnetic Waves**

Equations and Relations:

Speed, wavelength, and frequency of a wave
$v = \lambda f$

Beats:
$f_{\text{beat}} = |f_1 - f_2|$

Doppler Effect – moving observer:
$f' = (1 \pm u_o / v) f$

Doppler Effect – moving source:
$$f' = \left(\frac{1}{1 \mp u_s / v} \right) f$$

v: speed of the wave
u_o: relative speed of the observer
u_s: relative speed of the source

Doppler Effect for electromagnetic waves:
$$f' = f\left(1 \pm \frac{u}{c}\right)$$

u: relative speed between source and observer

Intensity as power per area:
$$I = \frac{P}{A}$$
$$I = \frac{P}{4\pi r^2} \quad \text{(point source at a distance } r\text{)}$$

Energy density:
$$u = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2\mu_0} B^2 = \varepsilon_0 E^2 = \frac{1}{\mu_0} B^2$$

Ratio of electric and magnetic field:
$E = cB$

Intensity:
$$I = u\,c = \frac{1}{2} c\varepsilon_0 E^2 + \frac{1}{2\mu_0} cB^2 = c\varepsilon_0 E^2 = \frac{c}{\mu_0} B^2$$

Momentum:
$$p = \frac{U}{c}$$

Radiation pressure:
$$pressure_{av} = \frac{I_{av}}{c}$$

1. An auditorium has organ pipes at the front and at the rear of the hall. Two identical pipes, one at the front and one at the back, have fundamental frequencies of 264 Hz at 20 ºC. During a performance, the organ pipes at the back of the hall are at 25 ºC, while those at the front are still at 20 ºC. What is the beat frequency when the two pipes sound simultaneously?
   (use: $v_{sound,20^\circ C} = 343 m/s$, $v_{sound,25^\circ C} = 346 m/s$ calculated with equation from thermodynamics: $v = \sqrt{\frac{\gamma RT}{M}}$)

2. A source of sound waves of frequency 1.0 kHz is stationary. An observer is traveling at 0.50 times the speed of sound.
   (a) What is the observed frequency if the observer moves toward the source?

(b) What is the observed frequency if the observer moves away from the source instead.

3. A source of sound waves of frequency 1.0 kHz is traveling through the air at 0.50 times the speed of sound.
   (a) Find the frequency of the sound received by a stationary observer if the source moves towards her.
   (b) Repeat if the source moves away from her instead.

4. You drive in a your car at a speed of 50 km/h and ambulance approaches from behind at a speed of 80 km/h. When the ambulance is at rest its siren produces sound at a frequency of 1050 Hz.
   (a) What is the frequency of the siren observed by you?
   (b) What is the wavelength of sound reaching you?

   - *The source and observer of a sound wave are both at rest with respect to the ground. The wind blows in the direction of source to observer. Is the observed frequency Doppler-shifted? Explain.*

5. A galaxy emits light at a wavelength of 656 nm. On earth the wavelength is measured to be 659.1 nm.
   (a) What is the speed of the galaxy relative to the earth?
   (b) Is the galaxy approaching or receding?

   - *What do cosmologist mean when the say the electromagnetic radiation from other galaxies is "red shifted"?*

   - *Can you distinguish between the case of a moving observer or moving source in the case of sound and electromagnetic waves?*

6. When light having vibrations with angular frequency ranging from 2.7×10^{15} rad/s to 4.7×10^{15} rad/s strikes the retina of the eye, it stimulates the receptor cells there and is perceived as visible light. What are the limits of the period and frequency of this light?

- *Microwave ovens, radio, radar, and x-rays utilize electromagnetic waves. Compare the energy, frequency and wavelengths of these waves to those of visible radiation.*

7. A lightning flash is seen in the sky and 8.2 s later the boom of the thunder is heard. The temperature of the air is 12 ºC. (use $v_{sound,12^\circ C} = 338 m/s$)
   How far away is the lightning strike?

- *During a thunderstorm, you can easily estimate your distance from a lightning strike. Count the number of seconds that elapse from when you see the flash of lightning to when you hear the thunder . The rule of thumb is that 5 seconds elapse for each mile distance. Verify that this rule of thumb is (approximately) correct. (One mile is 1.6 km and light travels at a speed of 3×10^8 m/s.)*

- *For an xyz coordinate system, if the E-vector is in the z direction, and the B-vector is in the x direction, what is the direction of propagation of the electromagnetic waves?*

8. The microwave background radiation leftover from the big bang has an average energy density of 4×10^{-14} J/m^3.
   (a) What is the rms and maximum value of the electric and magnetic component of this radiation?
   (b) Calculate the intensity of this radiation.

9. The average intensity of the sunlight reaching the earth is 1390 W/m^2.

   (a) What is the average radiation pressure due to the sunlight?
   (b) What is the maximum energy that a 5 x 8m solar panel could collect in 12 hours, if all sunlight is absorbed (the real efficiency of solar panels is much lower)?
   (c) Calculate the average force exerted by the light on the solar panel assuming it absorbs all incoming light.
   (d) Calculate the energy density of sunlight.

- *Suppose you triple the magnitude of the magnetic field of an electromagnetic wave. By what factor does the electric component of the wave change? By what factor changes the intensity of the wave?*

Additional Questions

1. In tennis a radar gun is often used to measure the speed of the ball. Describe how such a radar gun could work.

2. If a spaceship uses the radiation pressure of the sun, should it use sails that are reflection or absorbing?

3. If you move on a spaceship away from the sun, by how much does the intensity of the radiation decrease as you double the distance between you and the sun?