Homework No. 09 (Spring 2022)

PHYS 203B-001: COLLEGE PHYSICS

Department of Physics, Southern Illinois University–Carbondale

Due date: Wednesday, 2022 Apr 6, 10:00am, on D2L

Instructions

- To the extent to which you depend on resources to complete this homework is a measure of how much extra work you need to put in to master the related concepts.
- Describe your thought process in detail and organize it clearly. Make sure your answer has the correct units and the right number of significant digits.
- After completion, scan the pages as a single PDF file, and submit the file on D2L (Assessments → Assignments).

Problems

1. (**10 points.**) Assuming a straight-line path for radio communication, calculate the time-lag between the transmitter and receiver in the following cases. Use the equation

$$c = \frac{d}{t}, \tag{1}$$

where c is the speed of light, d is distance, and t is time. Show your work. Please use the Internet to find the relevant distances.

(a) Between two friends 30 km apart, in micro-seconds.

(b) Between diametrically opposite points on Earth, along a straight line passing through the center of Earth, in seconds. (In practice, radio signals use a path along the circumference of Earth and do not pass through Earth.)

(c) Between Earth and Moon, in seconds.

(d) Between Earth and Mars, in minutes.

(e) Between Earth and Pluto, in hours.

(f) Between Earth and the closest star to Sun, in years.

(g) Between Earth and the closest galaxy to Milky Way, in kilo-years.

(h) Between Earth and the edge of observable universe, in billion-years.

Solution

2. (**10 points.**) Light waves travel nearly a million times faster than sound waves in air. (Speed of sound is about 340 m/s.) With this in mind, estimate the distance to a lightning bolt from your position, if you counted three seconds between the flash and the sound of thunder.

   Solution

3. (**10 points.**) A rifle is fired along a valley with parallel vertical walls. The echo from one wall is heard 2.3 s after the rifle was fired. The echo from the other wall is heard 2.3 s after the first echo. How wide is the valley?

   Solution

4. (**10 points.**) Electromagnetic waves are oscillations of electric and magnetic fields that sustain each other using Faraday and Maxwell laws. The speed of all electromagnetic waves is the same in vacuum and is called the speed of light in vacuum and is given by

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}. \tag{2}$$

   In SI units c is chosen to be a whole number,

$$c = 299\,792\,458\,\frac{\text{m}}{\text{s}}. \tag{3}$$

   (a) The wave nature stipulates the relation between wavelength λ, frequency f, and speed c of the wave,

$$c = \lambda f. \tag{4}$$

   The time period $T = 1/f$, and the wavevector $k = 2\pi/\lambda$, are related quantities. Calculate the frequency associated with a monochromatic wave of red light of wavelength 632.8 nm.

   (b) The electromagnetic energy density is given by

$$u = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2\mu_0} B^2. \tag{5}$$

   Given that the red monochromatic wave consists of a maximum electric field strength of 20.0 V/m, determine the associated maximum magnetic field strength. (Hint: $E = cB$.) Calculate the electromagnetic energy per unit volume for the red light. Also, show that the electrical energy density is equal to the magnetic energy density.

   (c) The flux of the electromagnetic energy density, a measure of the flow rate of electromagnetic energy per unit area, is given by the Poynting vector

$$\vec{\mathbf{S}} = \frac{1}{\mu_0}\vec{\mathbf{E}} \times \vec{\mathbf{B}}. \tag{6}$$

   The electromagnetic momentum density is given by

$$\vec{\mathbf{G}} = \frac{1}{c^2}\vec{\mathbf{S}}. \tag{7}$$

Calculate the magnitude of the electromagnetic momentum density for the red light using the above expression.

Solution