Recitation 4 - Solutions

Conceptual Questions:

- What is the evidence that sound travels as a wave?

Sound exhibits **interference effects,** which are characteristic of waves.

- What is the evidence that sound transport energy?

Sound is a type of wave and therefore transports energy as any other wave. For example, sound can cause objects to vibrate, which is evidence that sound is a form of energy. In extreme cases, sound waves can even break objects. (See Figure 14-24 showing a goblet shattering from the sound of a trumpet.)

- The voice of a person who has inhaled helium sounds very high-pitched. Why?

Helium is much less dense than air, so the speed of sound in the helium is higher than in air. The wavelength of the sound produced does not change, because it is determined by the length of the vocal cords and other properties of the resonating cavity. The frequency therefore increases, increasing the pitch of the voice.

- The source of any sound wave is a vibrating object (strings, membranes, air column etc.). What are the sources of electromagnetic (EM) waves? Circle the *source terms* in the Maxwell equations below.

In spite of intense searches, no isolated magnetic poles (monopoles) have ever been observed. In which of the four Maxwell equations is embodied this experimental evidence?

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I + \mu_0 \varepsilon_0 \frac{d}{dt} \Phi_E; \qquad \oint \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \Phi_B; \qquad \oint_S \vec{B} \cdot d\vec{A} = 0; \qquad \oint_S \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\varepsilon_0}$$

EM waves are generated by accelerating electric charges (Giancoli, Ch 31-4). They are present in the Gauss's law for electricity with the term Q_{enc}/ε_0 where the enclosed charge Q can change in time and the Ampere-Maxwell law with the term $\mu_0 I$ where the current I can change in time.
The Gauss's law for magnetism does not have a term like Q_{enc}/ε_0 , thus it embodies the absence of static magnetic sources.

Problem R4.1

A highway overpass of length L was observed to resonate as one full loop ($L=\lambda/2$) when a small earthquake shook the ground vertically at 3 Hz. Use the concept of forced harmonic oscillator and resonance to describe the event.

The highway department put a support at the center of the overpass, anchoring it to the ground as shown in figure 15-41. What resonant frequency would you now expect for the overpass? It is noted that earthquakes rarely do significant shaking above 5 or 6 Hz. Did the modification do any good? Explain.

Problem R4.1 – Solution

The overpass sustains standing waves with wavelength ($2L/n$). Each of those frequencies represents resonances, which can couple to an external, driving oscillator such as an earthquake. The addition of the support will force the bridge to have its lowest mode of oscillation with a node at the center of the span, which would be the first overtone of the fundamental frequency. If the wave speed in the bridge material remains constant, then the resonant frequency will double, to 5 or 6 Hz. Since earthquakes don't do significant shaking at that frequency (i.e., it is out of resonance), the modifications would be effective at keeping the bridge from having large oscillations during an earthquake (see Fig. 14-26).

Problem R4.2

The electric field and magnetic field of an electromagnetic wave are

$$\vec{E} = E_0 \sin(kx - \omega t)\,\hat{y}, \qquad \vec{B} = B_0 \sin(kx - \omega t)\,\hat{z}.$$

Knowing the equations

$$\frac{\partial E}{\partial x} = -\frac{\partial B}{\partial t}, \qquad \frac{\partial B}{\partial x} = -\mu_0 \varepsilon_0 \frac{\partial E}{\partial t},$$

obtain a relation between the amplitudes of $\vec{E}$ and $\vec{B}$, and the speed of the wave.

Problem R4.2 – Solution

See Giancoli chapter 31-5.

Problem R4.3

Example 31-2, example 31-3