ISP220, fall 2021: In-Class Project #9; 15 pts

Quarks, Spacetime, and the Big Bang

Tuesday, October 5, 2021

Name: KEY Student #

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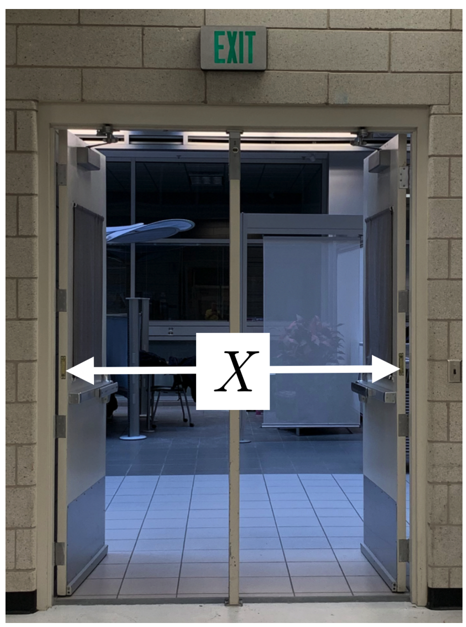
1 Waves, 10 points

Let's explore various waves that you experience in your lives:

1.1 Figure 1 is a picture of the door to our class.



x = 2 about

Figure 1: One way out.

Answer (1 point): In class we estimated the opening's width, X, to the nearest meter, to be:

X is about ____2____ m

The speed of sound in dry air is 343 m/s.

Answer (1 point): Given your estimate of the door opening, what is the frequency in Hz of a sound wave with that wavelength?

$v = f\lambda \Rightarrow f = v/\lambda = \frac{343 \text{ m/s}}{2\text{m}} = 171.5 \text{ s}^{-1}$

$f =$ ____171.5____ Hz

Here is a table of musical notes and their frequencies.

http://pages.mtu.edu/~suits/notefreqs.html

Answer (1 point): Which note on a piano would your frequency be closest to?

note: ____F_3____

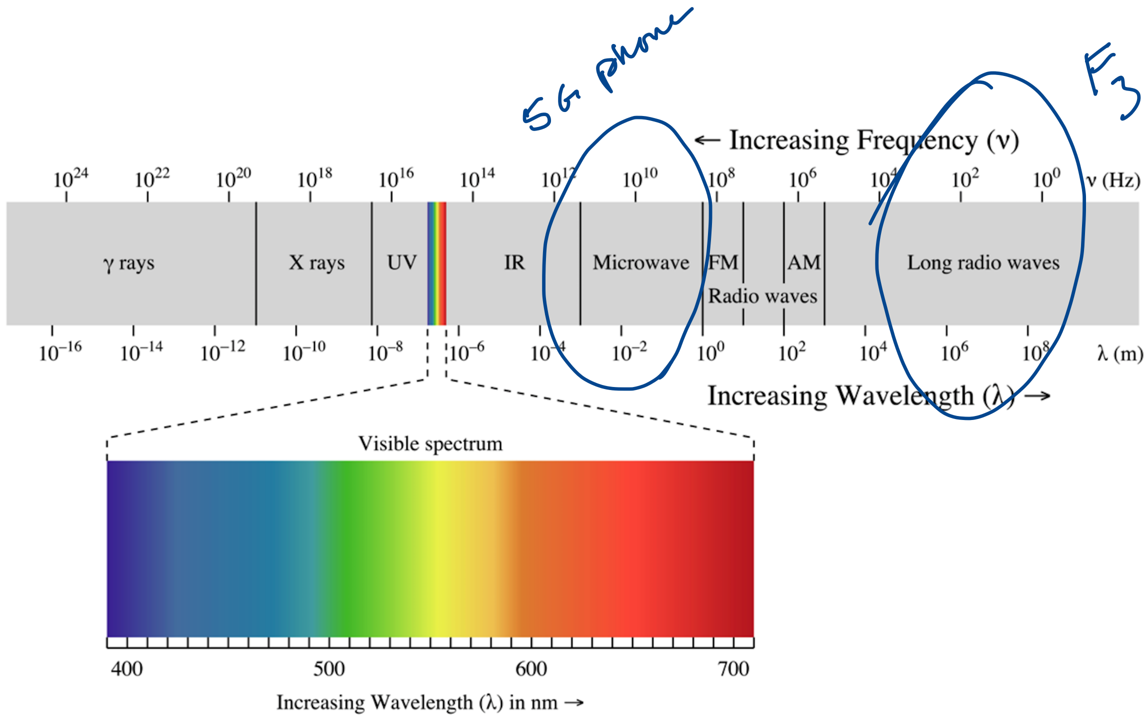


Figure 2: E&M spectrum.

Figure 2 shows the electromagnetic spectrum frequencies and wavelengths. Roughly which of the named electromagnetic bands (γ rays, X rays, UV, Visible, IR, Microwave, FM radio, AM radio, or long radio) would correspond to your door-sized wavelength?

1 point: Circle the range of the spectrum that roughly corresponds to the frequency and wavelength of your musical note.

1.2 The frequency of the high-speed 5G wireless signal ranges from about 25 - 39 GHz.

Pick the lowest of that band's range. You know the speed of that electromagnetic wave signal.

Answer (1 point): What is the wavelength of the electromagnetic wave emitted and absorbed by your shiny new 5G phone?

$25\,\text{GHz} = 25 \times 10^9\,\text{Hz} = 2.5 \times 10^{10}\,\text{Hz}$

$c = f\lambda$

$\lambda = \frac{c}{f} = \frac{3 \times 10^8\,\text{m/s}}{2.5 \times 10^{10}\,\text{s}^{-1}} \approx 1 \times 10^{-2}\,\text{m}$

$\lambda =$ 0.01 m

Answer (1 point): The diameter of the cell body of the neurons in your brain is about 0.1mm. What factor smaller is that than the 5G signal?

$$\frac{\text{cell}}{\lambda} = \frac{0.1\text{ mm}}{10^{-2}\text{ m}} = \frac{0.1 \times 10^{-3}\text{ m}}{10^{-2}\text{ m}} \simeq 10^{-2}$$

cell/signal = 0.01

1.3 An earthquake has various components of wave-like behavior, generally, a surface wave and a primary "P" wave that's underground.

That's the fastest one of the two. The frequency of such a wave is about $f = 10$ Hz and the wavelength is about 300 m.

Answer (2 points): What is the speed of a P Wave in an earthquake in m/s?

$$v = f\lambda = (10\text{ s}^{-1})(100\text{ m}) = 3000\text{ m/s}$$

$v =$ 3000 m/s

Answer (1 point): What is that speed in mph? Be prepared to be impressed.

$v =$ 6,700 mph !

1.4 The last visible feature of the remnants of the Big Bang is what's called the Cosmic X Background, or "CXB".

No, it's not really "CXB" but you're going to figure out what the "X" stands for of this radiation. It's electromagnetic radiation that's hung around the universe for 14 billion years and it's uniformly (well, almost uniformly) all around us. You know the speed, I'll tell you the wavelength: it's 2 mm, or 2×10^{-3} m.

Answer (1 point): What is the frequency of the CXB in Hz?

$c = f\lambda \Rightarrow f = c/\lambda = \frac{3\times10^8 \text{ m/s}}{2\times10^{-3} \text{ m}} = 1.5\times10^{11}$ Hz

$f =$ 1.5×10^{11} Hz

Answer (1 point): Google around for electromagnetic radiation of that frequency and tell me what "X" is?

X = microwave Cosmic Microwave Background

2 Build An Accelerator Complex, 7 points

Figure 3 shows a small accelerator complex with a beam that originates at the source, S, and then passes through two regions where beam operators can insert one or two "Radio Frequency Cavities" (RF cavities) to accelerate the beam. After the beam reaches the design energy, it's directed toward the experiment in the upper right hand corner. That requires bending the beam by passing it through the "magnet" region.

The beam designers have an inventory of available RF cavities and magnets. With cranes and lots of effort, the right pieces are selected and rigged into place in the RF1, RF2, and magnet regions.

Here are the parameters:

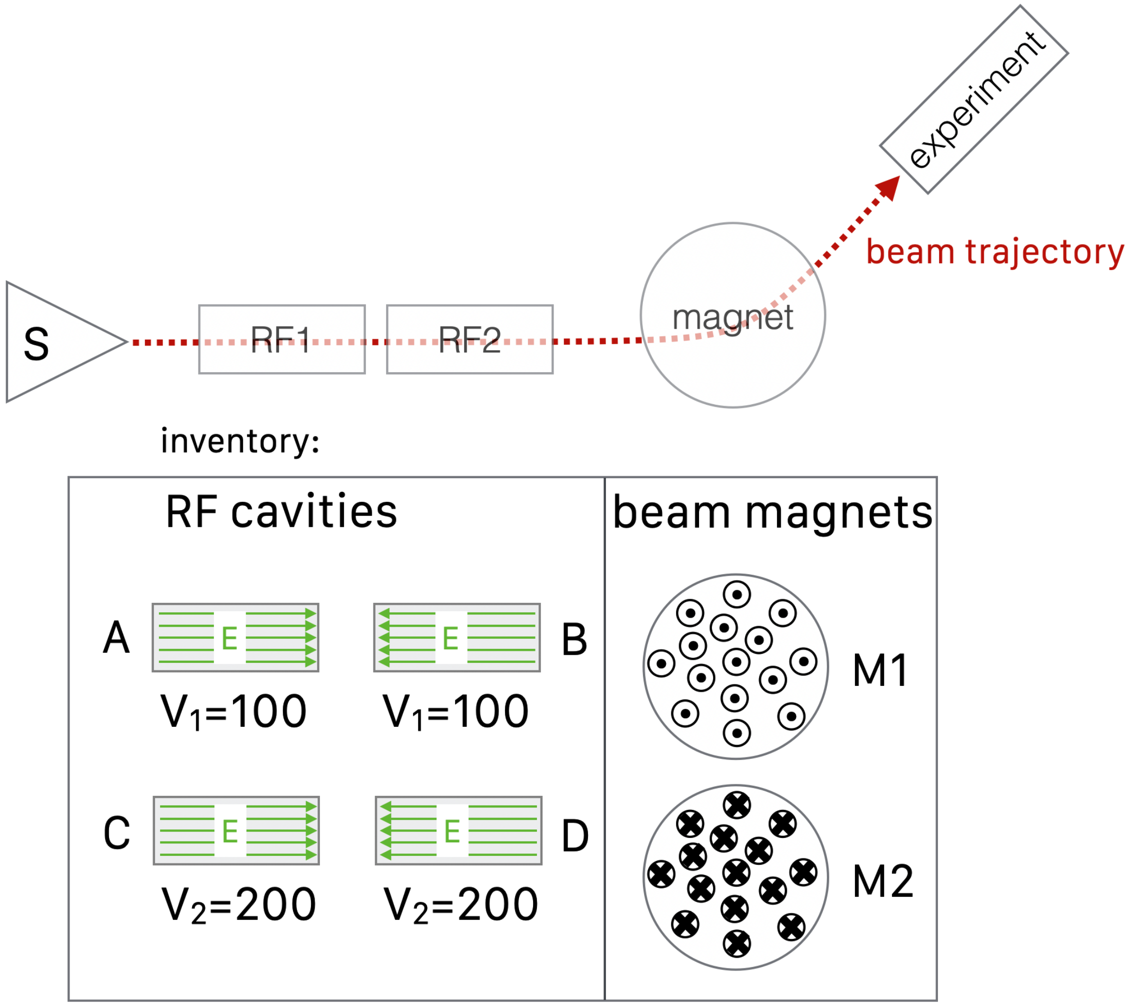


Figure 3: Our accelerator and beamline.

1. The beam particles have a charge of Q each.
2. There are four kinds of RF cavities:
   - Two cavities (A and B) have voltages of $V_1 = 100$ V and two (C and D) have $V_2 = 200$ V.
   - Each cavity can be set up with the electric field pointing right (A and C) or left (B and D) as shown.
   - There are two kinds of magnets in the inventory, M1 and M2, which are distin-

guished by the direction of the magnetic field that they each produce.

- The source produces particles with kinetic energies of 100 J.

What's chosen for the beam elements is what the physicists need for their experiment. The engineers know is that the kinetic energy that a particle receives in an electric field is:

$$U = QV.$$

Answer (1 point): The source produces particles with charge $Q = +5$ C (fake units as that's an absurd amount of charge!). The experiment needs particles with kinetic energies of $K = 600$ J. What magnet should they use, M1 or M2?

Magnet choice = M1

Answer (2 point): The source produces particles with charge $Q = +5$ C (fake units as that's an absurd amount of charge!). The experiment needs particles with kinetic energies of $K = 600$ J. Which combination of RF cavities should the engineers install?

need 600 − 100 J = 500 J from RF cavity

$U = QV \Rightarrow V = \frac{U}{Q} = \frac{500}{5} = 100$ V

RF cavity choice(s) = A

Answer (2 point): The source produces particles with charge $Q = +5$ C (fake units as that's an absurd amount of charge!). The experiment needs particles with kinetic energies of $K = 2100$ J. Which combination of RF cavities should the engineers install?

RF cavity choice(s) = need 2 C

2100 − 100 = 2000 J needed from RF

$V = \frac{U}{Q} = \frac{2000}{5} = 400$ V

so need 2 C