PH202-1G
Spring 2014

Worksheet February 26

Semiconductors

What is an *n*-type semiconductor? What kinds of mobile charges does an *n*-type semiconductor contain?

Material made from silicon doped with a group V atom, e.g. phosphorus, to create mobile negative charges.

What is a *p*-type semiconductor? What kinds of mobile charges does a *p*-type semiconductor contain?

Material made from silicon doped with a group III atom, e.g. boron, to create mobile positive charges.

What happens when you put an *n*-type semiconductor and a *p*-type conductor together? What is this arrangement called?

With an external voltage, current can flow from p to n but not from n to p. This is called a pn junction diode.

What does a transistor do?

Transistors (also called bipolar junctions) amplify ac voltages.

Electromagnetic waves

Describe an electromagnetic wave. What are its constituents? Does it require a medium? – no medium

An electromagnetic wave is composed of oscillating electric and magnetic fields perpendicular to the wave's velocity.

Give a mathematical expression for the speed of an electromagnetic wave in terms of its wavelength and frequency and in terms of fundamental constants. What is special about this speed?

$v = \lambda f = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$ Speed is constant $c = 3.00 \cdot 10^{8}\ m \cdot s^{-1}$

Define energy density, give its units of measurement, and describe three ways to express the energy density of an electromagnetic wave mathematically.

Energy density in energy per unit volume in $J \cdot m^{-3}$ or $N \cdot m^{-2}$

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

$u = \varepsilon_0 E^2$

$u = \frac{1}{\mu_0} B^2$

How are the magnitudes of the electric and magnetic fields in an electromagnetic wave related?

$E = cB$ for any point in time.

Define intensity, give its units of measurement, and describe a mathematical expression for the intensity of an electromagnetic wave.

Intensity is power per unit area in $W \cdot m^{-2}$ $S = \frac{P}{A} = cu$

Describe the Doppler effect qualitatively and give a mathematical expression for it.

Motion of an observer or a source of electromagnetic waves relative to each other causes a shift in frequency.

$f_{obs} = f_{source}\left(1 \pm \frac{v_{rel}}{c}\right)$

Use + if the source and observer are getting closer together. Use – if they are getting farther apart.

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What is polarized light? How does the intensity of polarized light relate to the intensity of unpolarized light?

Polarized light oscillates in one plane only. The intensity of polarized light is half of unpolarized light.

Give a mathematical expression for the intensity of polarized light which passes through a second polarizer.

$S = S_0 \cos^2 \theta$ S_0 is intensity after first polarization

θ is angle between polarizers.

Problems

1. You light a match in a pitch black room. The light from the match produces a maximum magnetic field of 20 nT on a 3 m square wall on the other side of the room. What is the maximum power generated by the match?

Intensity $S = \frac{P}{A} = cu = \frac{c}{\mu_0} B^2$

$P = \frac{c}{\mu_0} A B^2 = \frac{3.00 \cdot 10^8 \text{ m} \cdot \text{s}^{-1}}{4\pi \cdot 10^{-7} \text{ T} \cdot \text{m} \cdot \text{A}^{-1}} (3 \text{ m})^2 (20 \cdot 10^{-9} \text{ T})^2 = \boxed{0.86 \text{ W}}$

2. A spaceship is flying directly away from a planet with a speed of $6.0 \cdot 10^7$ m·s⁻¹. The planet receives a radio signal from the spaceship with a frequency 940 MHz. What was the frequency of the signal emitted by the ship?

Since the spaceship is flying away, we must use a negative sign in the Doppler equation.

$f_{obs} = f_s \left(1 - \frac{v_{rel}}{c}\right)$ $\frac{c}{\lambda_{obs}} = \frac{c}{\lambda_s}\left(1 - \frac{v_{rel}}{c}\right)$

$f_s = \frac{f_{obs}}{\left(1 - \frac{v_{rel}}{c}\right)} = \frac{940 \text{ MHz}}{1 - \frac{6.0 \cdot 10^7 \text{ m} \cdot \text{s}^{-1}}{3.0 \cdot 10^8 \text{ m} \cdot \text{s}^{-1}}} = 1175 \text{ MHz} = \boxed{1.2 \text{ GHz}}$

3. An electromagnetic wave with an intensity of 700 W·m⁻² passes through a polarizer. The polarized light then passes through a second polarizer, and the resulting wave has an intensity of 150 W·m⁻². What is the angle between the polarizers?

First polarizer reduces intensity by half: $S_1 = \frac{S_0}{2} = \frac{700 \text{ W} \cdot \text{m}^{-2}}{2} = 350 \text{ W} \cdot \text{m}^{-2}$

Second polarizer obeys Malus's law: $S_2 = S_1 \cos^2 \theta$

$\theta = \cos^{-1}\left(\sqrt{\frac{S_2}{S_1}}\right) = \cos^{-1}\left(\sqrt{\frac{150 \text{ W} \cdot \text{m}^{-2}}{350 \text{ W} \cdot \text{m}^{-2}}}\right) = \boxed{49^\circ}$