Phys 104: College Physics Name Key

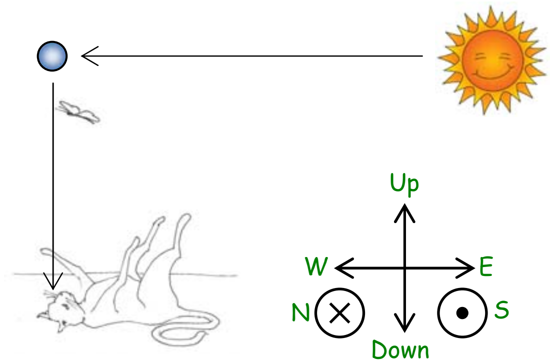
Exam 3

Friday, April 16, 2010

I. Very Short Answer:

1)[3] A cat plays with a butterfly at dawn and looks directly up at light from the sun rising in the east that has been scattered by a molecule in the atmosphere. The light the cat sees is

a) unpolarized (randomly polarized)
b) mostly polarized east/west
c) mostly polarized up/down
d) mostly polarized north/south



2)[3] Green light (λ_G = 500 nm) is incident on a double slit. The first order maximum diffracts at an angle of 4° and is viewed on a screen 2 m away. If the light is changed from green to red (λ_R = 600 nm),

a) the diffraction pattern will disappear from the screen
b) the first order red light will be diffracted at an angle of 2.6°
c) the first order red light will be diffracted at an angle of 3.3°
d) the first order red light will be diffracted at an angle of 4.8°

$$d\sin\theta = m\lambda$$

For green:

$$d = \frac{(1)(500)}{\sin(4)} = 7168 \text{ nm}$$

For red:

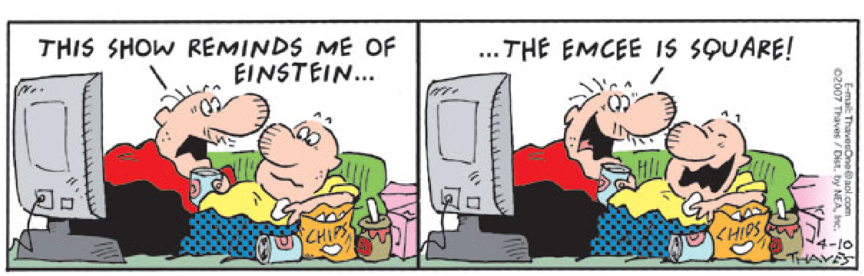
$$\sin\theta = \frac{(1)(600)}{7168} = 0.084 \quad \Rightarrow \quad \theta = 4.8°$$

3)[4] A real object in front of a lens produces an image with a magnification of m = -2.

a) is the image virtual or real?
b) is the image inverted or upright?
c) is the lens converging or diverging?
d) is the object distance greater than 2f, between f and 2f or less than f?

Circle the best answer on each line

$$m = -\frac{q}{p} = -2 \quad \Rightarrow \quad q = 2p \qquad \frac{1}{f} = \frac{1}{p} + \frac{1}{q} = \frac{1}{p} + \frac{1}{2p} = \frac{3}{2p} \quad \Rightarrow \quad p = \frac{3}{2}f$$

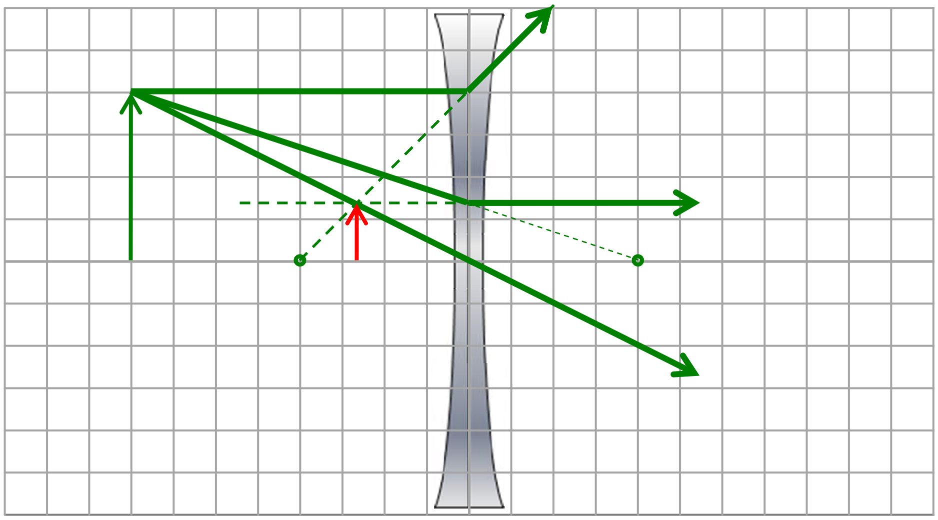


II. Short Answer:

1)[10] On the grid below, an object 4.0 squares tall is 8 squares in front of a lens with a focal length of -4 squares.

a) Make a scale sketch of the object, lens and at least 2 rays to form the image.

b) Describe the image by choosing from the following pairs:



real or virtual

upright or inverted

larger or smaller

2)[10] Red light (λ = 680 nm) shines through a grating with 5550 slits/cm onto a screen 3.5 m away.

a) What is the distance between adjacent slits on the grating?

b) What is the angle to the first order maximum on the screen?

a) $$d = \frac{0.01\text{ m}}{5550\text{ slits}} = 1.80\times10^{-6}\text{ m}\left(\frac{1\text{ nm}}{1\times10^{-9}\text{ m}}\right) = 1800\text{ nm}$$

b) $$d\sin\theta = m\lambda \quad\Rightarrow\quad \sin\theta = \frac{m\lambda}{d} = \frac{(1)(680)}{(1800)} = 0.378 \quad\Rightarrow\quad \theta = 22.2^\circ$$

3)[10] Using the periodic table, fill in the missing particles and the type of decay reaction in the following nuclear reactions. Be sure to include the atomic number, Z, and the mass number, A, and the particle ${}^{A}_{Z}X$.

a) ${}^{103}_{44}Ru \Rightarrow {}^{103}_{45}Rh + {}^{0}_{-1}e$ is β^- decay.

b) ${}^{61}_{28}Ni \Rightarrow {}^{61}_{28}Ni + {}^{0}_{0}\gamma$ is γ, gamma decay.

c) ${}^{7}_{4}Be + {}^{0}_{-1}e \Rightarrow {}^{7}_{3}Li$ is e^- capture decay.

d) ${}^{15}_{8}O \Rightarrow {}^{15}_{7}N + {}^{0}_{+1}e$ is β^+ decay.

e) ${}^{238}_{92}U \Rightarrow {}^{234}_{90}Th + {}^{4}_{2}\alpha$ is α, alpha decay.

III. Problems (Do 3 of 4):

Color	Wavelength
Violet	410
Blue	470
Green	550
Yellow	580
Orange	610
Red	660

1)[20] An oil film (n_o = 1.40) floating on water (n_w = 1.33) is illuminated by white light at nearly normal incidence. The film is 280 *nm* thick.

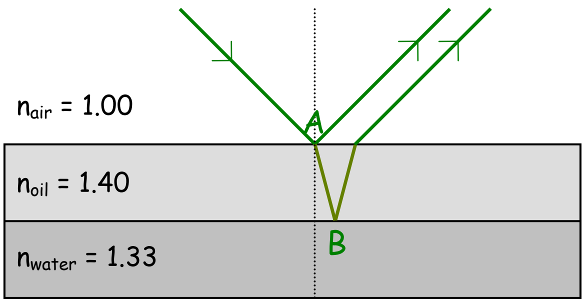
a) What is the phase shift for the ray that reflects off the oil at A?

180°, π or $\frac{1}{2}\lambda$

b) What is the phase shift for the ray that reflects off the oil at B?

no phase shift

c) Explaining your work as you go, find the wavelength and identify the color of visible light that is most strongly enhanced.



Since only one reflection has a phase shift, for them to constructively interfere they must be in phase, so the path difference must be some odd number of half wavelengths:

$$2t = \left(m+\frac{1}{2}\right)\lambda_{oil} = \left(m+\frac{1}{2}\right)\frac{\lambda}{n_{oil}}$$

Solving for λ:
$$\lambda = \frac{2t}{\left(m+\frac{1}{2}\right)}$$

Calculate λ for various m's:

$$\lambda_0 = \frac{2tn_{oil}}{\left(0+\frac{1}{2}\right)} = 4tn_{oil} = 4(280)(1.4) = 1568\text{nm}$$

$$\lambda_1 = \frac{2tn_{oil}}{\left(1+\frac{1}{2}\right)} = \frac{4}{3}tn_{oil} = \frac{1568}{3} = 522.6\text{ nm}$$

$$\lambda_2 = \frac{2tn_{oil}}{\left(2+\frac{1}{2}\right)} = \frac{4}{5}tn_{oil} = \frac{1568}{5} = 313.6\text{ nm}$$

Since the m = 1 value is the only one in the visible portion of the spectrum,

$$\boxed{\lambda = 523\text{ nm} = \text{bluish green}}$$

III. Problems (Do 3 of 4):

2)[20] Strontium-90 $\left({}^{90}_{38}\mathrm{Sr}\right)$ is produced in nuclear fission. It decays to ${}^{90}\mathrm{Y}$ with a half-life of 28.8 years.

${}^{90}_{38}\mathrm{Sr}$: m_{atom} = 89.907 737 6 u
${}^{90}\mathrm{Y}$: m_{atom} = 89.907 151 4 u

- **a)** Write down the decay reaction (include the Z of Y).
- **b)** How many atoms are present initially in 2.0 kg of ${}^{90}_{38}\mathrm{Sr}$
- **c)** What is the initial activity of 2.0 kg of ${}^{90}_{38}\mathrm{Sr}$ in Ci and Bq?
- **d)** What is its activity in 1000 yr?

a) Write out the reaction.

$$ {}^{90}_{38}\mathrm{Sr} \Rightarrow {}^{90}_{39}\mathrm{Y} + {}^{0}_{-1}e + \bar{\nu} $$

b) Find N in 2.0 kg of ${}^{90}_{38}\mathrm{Sr}$:

$$ N = \frac{m_{sample}}{m_{Sr,atom}} = \frac{2.0 \text{ kg}}{(89.9077376 \text{ u})\left(1.660539 \times 10^{-27} \text{ kg/u}\right)} = 1.3396 \times 10^{25} \text{ atoms} $$

Find λ from $T_{\frac{1}{2}}$:

$$ T_{\frac{1}{2}} = \frac{\ln(2)}{\lambda} \quad \Rightarrow \quad \lambda = \frac{\ln(2)}{T_{\frac{1}{2}}} = \frac{\ln(2)}{28.8 \text{ yr}} = 0.0240676 \text{ yr}^{-1} $$

c) Find R from N & λ:

$$ R = N\lambda = \left(1.3396 \times 10^{25}\right)\left(0.02407 \text{ yr}^{-1}\right) = 3.2244 \times 10^{23} \frac{\text{decays}}{\text{year}}\left(\frac{1 \text{ yr}}{365*24*3600 \text{ sec}}\right) $$

$$ R = 1.022356 \times 10^{16} \text{ Bq}\left(\frac{1 \text{ Ci}}{3.7 \times 10^{10} \text{Bq}}\right) $$

Quantum Mechanic

$$ \boxed{R = 1.02 \times 10^{16} \text{ Bq} = 2.763 \times 10^{5} \text{ Ci}} $$

d) Use the decay of the rate:

$$ R = R_0 e^{-\lambda t} = \left(1.022356 \times 10^{16}\right) e^{\left(-0.0240676 \text{ yr}^{-1}\right)(1000 \text{ yr})} $$

$$ \boxed{R = 3.607 \times 10^{5} \text{ Bq}} $$

III. Problems (Do 3 of 4):

3)[20] Toby, the goldfish, lives in a tank of water (n_w = 1.33) with glass sides (n_g = 1.51).

a) As Toby looks up out of the tank (water to air), he sees a light at an angle of 20°. What is the actual angle? Draw the normal, rays and light bulb and label the angles on the top diagram.

b) Is there an angle where he can no longer see out of the water? Explain and find the angle if it exists. Draw the normal and rays and label the angles on the middle diagram.

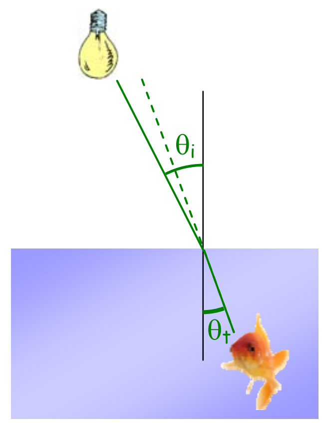
d) There is a light on the pump in the bottom corner of Toby's tank which he can see reflected off the top surface of the water. At what angle will the reflected light be totally polarized? Draw the polarization directions of the incident and reflected rays and label the angles on the bottom diagram

a) Use Snell's Law for a ray coming from the light, refracted to Toby at 20°.

$$n_i \sin\theta_i = n_t \sin\theta_t$$

$$\sin\theta_i = \frac{n_t}{n_i}\sin\theta_t = \frac{1.33}{1}\sin(20) = 0.455$$

$$\theta_1 = \sin^{-1}(0.455) = 27.1°$$

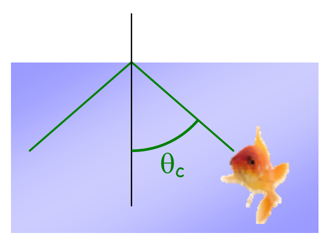


b) Use Snell's Law for a ray for the critical angle

$$n_i \sin\theta_c = n_t \sin(90°) \Rightarrow \theta_c = \sin^{-1}\left(\frac{n_t}{n_i}\right)$$

$$\theta_c = \sin^{-1}\left(\frac{1}{1.33}\right) = 48.8°$$

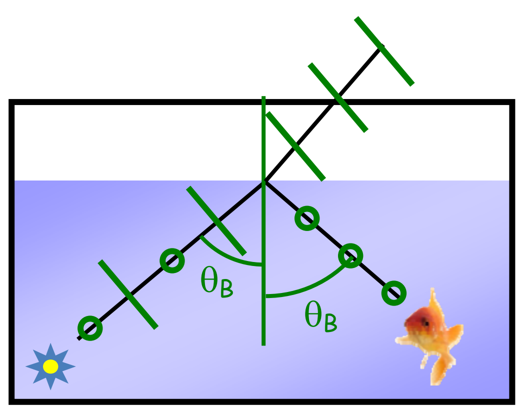
Toby can't see out at angles greater than 48.8°



c) The light will be totally polarized at Brewster's angle (ray going from water to air)

$$\theta_B = \tan^{-1}\left(\frac{n_t}{n_i}\right) = \tan^{-1}\left(\frac{1}{1.33}\right) = 36.9°$$

The light will be totally polarized perpendicular to the plane of the page as shown by the solid circles.



III. Problems (Do 3 of 4):

4)[20] A dentist holds a small mirror 1.9 cm from the surface of a patient's tooth. The image is upright and 5.0 times larger than the tooth.

- **a)** Is the image real or virtual?
- **b)** Where is the image located?
- **c)** Is the mirror convex or concave? What is its focal length?
- **d)** If the mirror is moved closer to the tooth, will the image get larger or smaller?
- **e)** For what range of object distances does the mirror produce an upright image?

a) Since it's a real object and m is positive, q must be negative so the image is **virtual**.

b) Find q from the magnification:

$$m = -\frac{q}{p} \quad \Rightarrow \quad q = -mp = -(5)(1.9) = -9.5 \text{ cm}$$

So the image is 9.5 cm behind the mirror.

c) To create a larger image, the mirror has to be concave so the focal length is positive and found from the image and object distances.

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \quad \Rightarrow \quad f = \frac{pq}{q+p} = \frac{(1.9)(-9.5)}{-9.5+1.9} = +2.38 \text{ cm}$$

f is positive so it is, indeed, a concave mirror.

d) The virtual image tells us that the object must be inside the focal length of the mirror. Solving the lens equation for q shows that inside the focal length, where p < f, as p gets smaller, p – f gets larger, so the image will get SMALLER.

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p} \quad \Rightarrow \quad q = \frac{fp}{p-f}$$

e) The mirror will produce an upright image when the object is inside the focal length so p must be between 0 cm and 2.38 cm.

$$0 \le p \le 2.38 \text{ cm}$$

Constants to know and love:

- $k = 9 \times 10^9$ N-m²/C²
- $G = 6.67 \times 10^{-11}$ N-m²/kg²
- $e = 1.60 \times 10^{-19}$ C
- $m_e = 9.11 \times 10^{-31}$ kg
- $m_p = 1.67 \times 10^{-27}$ kg
- $c = 3.0 \times 10^8$ m/s
- $N_A = 6.02 \times 10^{23}$ things/mole
- $\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N-m²
- $\mu_0 = 4\pi \times 10^{-7}$ T-m/A
- m_n=1.0086649 u
- m_p=1.0072765 u
- m_e=0.0005486 u
- 1 u = 931.494 MeV/c^2
- c^2 =931.494 MeV/u
- 1 Ci =3 x 10^{10} Bq