PHY294 Exam #3

Name:_____ Student #:_____

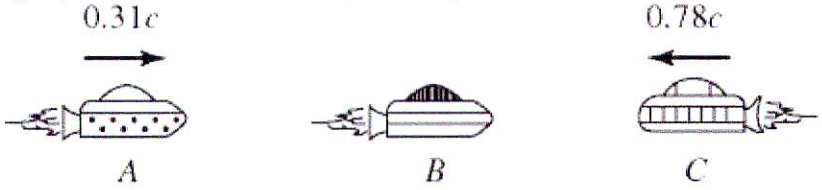
Show work for all problems involving numerical answers. Include units in answer where appropriate.

Some physical constants:

$c=3X10^8$ m/s

1) The special theory of relativity predicts that there is an upper limit to the speed of a particle. It therefore follows that there is also an upper limit on the following properties of a particle.
A) the kinetic energy
B) the total energy
C) the linear momentum
D) more than one of these
E) none of these

2) Three spaceships *A*, *B*, and *C* are in motion, as shown in the figure. The commander on ship *B* observes ship *C* approaching with a relative velocity of 0.78*c*. The commander also observes ship *A*, advancing in the rear, with a relative velocity of 0.31*c*. What is the velocity of ship *C*, relative to an observer on ship *A*?



have to add velocities using relativistic equation

$$\frac{u+v}{1+\frac{uv}{c^2}} = \frac{0.31c + 0.78c}{1+\frac{(0.31c)(0.78c)}{c^2}} = \frac{1.09c}{1.24} = 0.88c$$

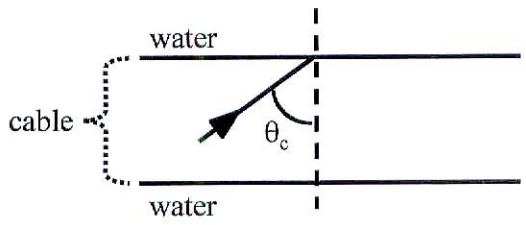
3) Assume that a certain city consumes electrical energy at an average rate of 2.0×10^9 W. What would be the mass change in producing enough energy to keep this city running for 21 weeks?

$E = mc^2 \quad m = E/c^2$

$E = 2\times10^9 \text{ J/s} \times 3600 \text{ s/hour} \times 24 \text{ hours/day} \times 7 \text{ days/week} \times 21 \text{ weeks} = 2.54\times10^{16} \text{ J}$

$$E/c^2 = \frac{2.54\times10^{16} \text{ J}}{(3\times10^8 \text{ m/s})^2} = 0.28 \text{ kg}$$

4) A fiber optic cable (n=1.50) is submerged in water (n=1.33). What is the critical angle for light to stay inside the cable?



$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{1.33}{1.50} = 0.89$

$\theta_c = 62.5°$

5) An object is placed 100 cm in front of a diverging lens with a focal length of magnitude 25 cm. A converging lens having a focal length of magnitude 33.33 cm is placed 30 cm past the first lens. Where is the final image formed?

A) 30 cm after the second lens
B) 20 cm in front of the first lens
C) 3.0 meters before the second lens
D) 100 cm after the second lens
E) 3.0 cm before the second lens

First lens

$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$

$\frac{1}{100\,cm} + \frac{1}{q} = \frac{1}{-25\,cm}$

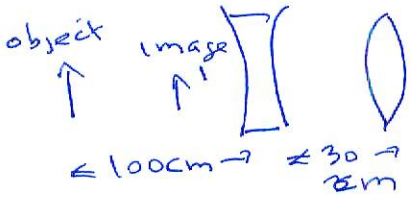


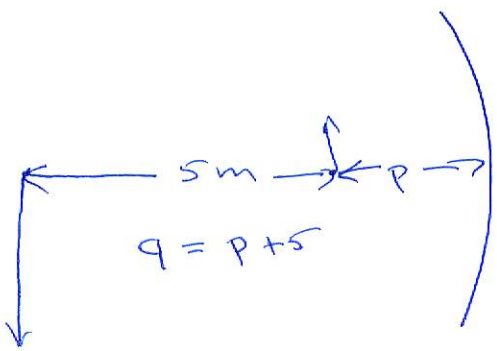
image 2 $q = -20\,cm$

image of first lens is object of second

$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ $\quad \frac{1}{50\,cm} + \frac{1}{q} = \frac{1}{f} = \frac{1}{33.3\,cm}$

$20+30$ $\quad q = 100\,cm$

6) A spherical mirror is to be used to form an image five times the size of an object on a screen located 5 m from the object. What type of mirror is required? Where should the mirror be positioned relative to the object?



Real image → has to be concave mirror

$m = -5 = -\frac{q}{p}$

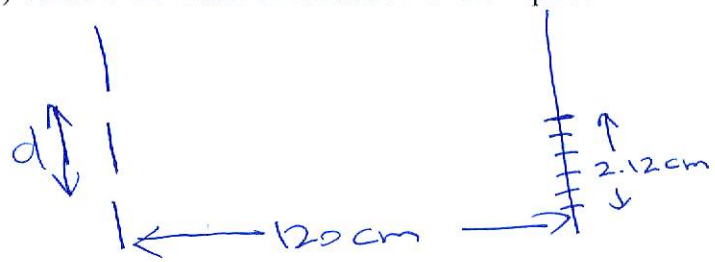
$\frac{p+5}{p} = 5$

$4p = 5m \quad p = 1.25\,m$

7) As an electromagnetic wave travels through free space, its speed can be increased by

a) increasing its frequency
b) increasing its energy
c) increasing both its energy and momentum
d) all of the above will increase its speed
e) none of the above will increase its speed

8) Monochromatic laser light of frequency 5.20×10^{14} Hz is shown on a pair of thin parallel slits, and the pattern is viewed on a screen 1.20 m away. The fifth bright fringes (not counting the central fringe) occur at ±2.12 cm on either side of the central bright fringe. The entire apparatus is now immersed in a transparent liquid. When the experiment is repeated, the fifth bright fringes now occur at ±1.43 cm from the central bright fringe. ($c = 3.00 \times 10^8$ m/s)
(a) How far apart are the slits?
(b) What is the index of refraction of the liquid?



$d \sin\theta = m\lambda$

$d \sin\theta_5 = 5\lambda$

$d = \frac{5\lambda}{\sin\theta_5}$

$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{ m/s}}{5.2 \times 10^{14} \text{ Hz}}$

$= 5.77 \times 10^{-7}$ m

$\sin\theta_5 \approx \frac{2.12 \text{ cm}}{120 \text{ cm}}$

$= 0.0177$

$d = 0.000169$ m

$= 0.000163$ m

$d \sin\theta' = m\lambda_n \quad \sin\theta_5'$

$d \sin\theta_5' = 5\lambda/n \quad = \frac{1.43 \text{ cm}}{120 \text{ cm}}$

$n = \frac{5\lambda}{d \sin\theta_5'} \quad = 0.0119$

$n = \frac{5(5.77 \times 10^{-7} \text{ m})}{(1.63 \times 10^{-4} \text{ m})(0.0119)} = 1.49$

9) When light goes from one material into another material having a HIGHER index of refraction
A) its speed, wavelength, and frequency all decrease.
B) its speed and wavelength decrease, but its frequency stays the same.
C) its speed decreases but its wavelength and frequency both increase.
D) its speed decreases but its frequency and wavelength stay the same.
E) its speed increases, its wavelength decreases, and its frequency stays the same.

10) An object is placed in front of a lens which forms an image of the object.
A) If the lens is convex, the image cannot be virtual.
B) If the image is real, then it is also inverted.
C) If the image is real, then it is also upright.
D) If the image is virtual, then it is also inverted.
E) If the image is virtual, the lens must be a diverging lens.

11) A cube has a density of 2000 kg/m^3 while at rest in the laboratory. What is the cube's density as measured by an experimenter in the laboratory as the cube moves through the laboratory at 90% of of the speed of light perpendicular to one of the faces.

$$\gamma = \frac{1}{\sqrt{1-v^2/c^2}} = \frac{1}{\sqrt{1-0.9^2}} = 2.29$$

Volume $= L^3$ (from cube's perspective)

Volume $= L^2 \times \frac{L}{2.29} = 0.436\, L^3$ (from lab perspective)

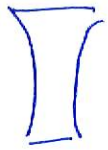
So density $= 2.29 \times 2000\ kg/m^3$

$= 4588\ kg/m^3$

also relativistic increase of energy but we won't worry about that

12) A double-concave lens has equal radii of curvature of 15.1 cm. An object placed 14.2 cm from the lens forms a virtual image 5.29 cm from the lens. What is the index of refraction of the lens material?

A) 1.90
B) 1.98
C) 1.82
D) 1.77
E) 1.67



$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

$$\frac{1}{14.2\,cm} + \frac{1}{-5.29\,cm} = \frac{1}{f}$$

$f = -8.43$ cm (cross-check: expect negative focal length for diverging lens)

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{-8.43\,cm} = (n-1)\left(\frac{1}{-15.1\,cm} - \frac{1}{15.1\,cm}\right)$$

$n = 1.90$