Physics 2020-003  
Final (A) – 4 May 2015

Part A: Hard Multiple Choice (20 points total, 2 points each, Circle Best Answer).

1. Two ions have the same positive charge. When they are at a distance of $3.68 \times 10^{-8}$ m from each other, they each experience an electric force of magnitude $6.13 \times 10^{-12}$ N. What is the charge on each particle?
   
   a) $9.61 \times 10^{-19}$ C  
   b) $3.20 \times 10^{-19}$ C  
   c) $6.22 \times 10^{-19}$ C  
   d) $16.0e + \frac{Z}{V^2}$  
   e) $24.0e$

   
   $F_e = \frac{9e_0}{r_e^2}, \sqrt{\frac{F_e}{E}} = \sqrt{\frac{9e_0}{F_e}} = \sqrt{\frac{(8.99 \times 10^9 \text{N} \cdot \text{m}^2/ \text{C}^2)(3.68 \times 10^{-8} \text{m})^2}{6.13 \times 10^{-12} \text{N}}} = 9.61 \times 10^{-19} \text{C}$

2. An alpha particle has a charge of $2.00e$. How far from this alpha particle would we experience an electric field strength of $5.84 \times 10^{-4}$ N/C?
   
   a) $1.09 \text{ nm}$  
   b) $13.6 \text{ \mu m}$  
   c) $2.22 \text{ mm}$  
   d) $16.2 \text{ cm}$  
   e) $8.90 \text{ m}$

   $E = \frac{Q}{E} \sqrt{\frac{9e_0}{F_e}} = \sqrt{\frac{8.45 \times 10^{-9} \text{C}^2/(2 \times 1.60 \times 10^{-19} \text{C})}{5.84 \times 10^{-4} \text{N/C}}} = 2.22 \times 10^{-3} \text{ m}$

3. A resistor is connected to a 12.0 V battery. If a current of 14.6 mA is flowing through the resistor, what is the resistance of this resistor?
   
   a) 0.175 $\Omega$  
   b) 1.22 $\Omega$  
   c) 333 $\Omega$  
   d) 175 $\Omega$  
   e) 822 $\Omega$

   $\Delta V = IR, R = \Delta V \frac{1}{I} = \frac{12.0 \text{V}}{14.6 \times 10^{-3} \text{A}} = 822 \Omega$

4. A 12.5 gram mass is connected to a spring and this spring is connected to a wall. This mass is pulled in the horizontal direction and released from rest. This mass then oscillates back and forth about the equilibrium position following simple harmonic motion. If the mass experiences a force of 134 N when it is at the $-16.2 \text{ cm}$ mark, what is the spring constant of this spring?
   
   a) 8.27 N/m  
   b) 13.4 N/m  
   c) 827 N/m  
   d) 1230 N/m  
   e) 1580 N/m

   $F_x = -kx, F_x = -\frac{134 \text{N}}{16.2 \times 10^{-2} \text{m}} = 827 \text{N/m}$

5. A pendulum oscillates at small angles with a period of 3.22 seconds on the surface of the Earth. How long is the rod that connects the bob (i.e., the mass) to the pivot point?
   
   a) 2.57 m  
   b) 38.9 cm  
   c) 3.60 m  
   d) 116 cm  
   e) 5.89 m

   $T = \frac{2\pi}{\sqrt{\frac{L}{g}}} \implies T^2 = \frac{4\pi^2 L}{g}$

   $L = \frac{gT^2}{4\pi^2} = \frac{(9.80 \text{ m/s}^2)(3.22 \text{s})^2}{4\pi^2} = 2.57 \text{m}$
6. A thin spherical mirror reflects a real image of a real object. The distance of this object from the mirror is 49.2 cm. If the image is one third the size of the object, how far from the mirror will the image be located?

a) 6.09 mm  
\[ h = \frac{h'}{n} \]

b) 16.4 cm  
\[ h = -\frac{h'}{n} \]

c) 36.0 cm  
\[ h = -\frac{h'}{n} \]

d) 77.2 cm  
\[ h = -\frac{h'}{n} \]

e) 148 cm  
\[ h = -\frac{h'}{n} \]

7. Light travels at a velocity of \(3.67 \times 10^7\) m/s in a transparent material. What is the index of refraction of this material?

a) 1.52  
\[ n = \frac{c}{v} = \frac{3.00 \times 10^8}{3.67 \times 10^7} = 8.17 \]

b) 2.67  
\[ n = \frac{c}{v} = \frac{3.00 \times 10^8}{3.67 \times 10^7} = 8.17 \]

c) 8.17  
\[ n = \frac{c}{v} = \frac{3.00 \times 10^8}{3.67 \times 10^7} = 8.17 \]

d) 13.6  
\[ n = \frac{c}{v} = \frac{3.00 \times 10^8}{3.67 \times 10^7} = 8.17 \]

e) 22.3  
\[ n = \frac{c}{v} = \frac{3.00 \times 10^8}{3.67 \times 10^7} = 8.17 \]

8. Coherent light passes through a double slit with a separation of 2.88 mm between the slits where each slit is 0.333 mm wide. An interference pattern is seen on a viewing screen that is 14.6 m away from the slit plane. If the center of the second-order bright fringe appears 4.56 mm from the center of the zeroth-order maximum, what is the wavelength of this light?

a) 14.6 cm  
\[ \gamma = \frac{\lambda L}{d} \]

b) 0.333 mm  
\[ \lambda = \frac{3k \times 10^{-6}}{m} \]

c) 4.64 nm  
\[ \lambda = \frac{3k \times 10^{-6}}{m} \]

d) 52.0 nm  
\[ \lambda = \frac{3k \times 10^{-6}}{m} \]

e) 450 nm  
\[ \lambda = \frac{3k \times 10^{-6}}{m} \]

9. One of the brightest carbon stars in the sky is TX Psc which has an angular size \(9.31 \times 10^{-3}\) arcseconds (= \(4.51 \times 10^{-8}\) radians). How big of a telescope (in terms of circular diameter) would one need in space just to see this star as a disk instead of a point of light at 500 nm?

a) 45.6 m  
\[ \theta = \frac{\lambda D}{D} \]

b) 65.4 m  
\[ \theta = \frac{\lambda D}{D} \]

c) 13.5 m  
\[ \theta = \frac{\lambda D}{D} \]

d) 56.7 m  
\[ \theta = \frac{\lambda D}{D} \]

e) 1.00 m  
\[ \theta = \frac{\lambda D}{D} \]

10. A high resolution spectrometer has a resolving power of 42,000 and a spectral resolution of 0.0236 nm for a spectral line at a certain wavelength. What is the wavelength of this spectral line?

a) 991 nm  
\[ R = \frac{\lambda}{\Delta \lambda} \]

b) 3970 Å  
\[ R = \frac{\lambda}{\Delta \lambda} \]

c) 9.80 nm  
\[ R = \frac{\lambda}{\Delta \lambda} \]

d) 6560 Å  
\[ R = \frac{\lambda}{\Delta \lambda} \]

e) 422 nm  
\[ R = \frac{\lambda}{\Delta \lambda} \]
Part B: Easy Multiple Choice (20 points total, 1 point each, Circle Best Answer).

11. Who discovered that electric charge comes in two different types, positive and negative?
   a) Ampere  b) Watt  c) Franklin  d) Maxwell  e) Millikan

12. Materials in which electric charge does not move freely in response to an electric force are called
   a) capacitors  b) inductors  c) conductors  
   d) insulators  e) thermistors

13. For an ohmic device, as temperature increase, what also must increase?
   a) capacitance  b) charge  c) resistance  d) current  e) inductance

14. The superposition principle can best be described by
   a) Capacitance increases when a dielectric is inserted between the two conducting plates.
   b) Mass increases without bound as the velocity of a mass approaches the speed of light.
   c) The apparent motion of a body exceeding the speed of light results from a combination of
      relativity and the viewing geometry.
   d) The initial and final position of the motion of a tachyon is in hyperspace.
   e) The final value of some parameter is equal to the sum of its parts.

15. The measure of a coulomb of charge per second is called a(n)
   a) volt  b) watt  c) ohm  d) ampere  e) farad

16. Which parameter is measured in ohm-meters?
   a) resistance  b) capacitance  c) inductance
   d) lever arm  e) none of these

   Resistivity
17. Natural magnets are also called
   a) loadstones    b) limestones    c) rubies    d) electromagnets    e) Carl

18. Any mass that obeys Hooke’s law will follow what type of path/motion?
   a) circular orbits
   b) simple harmonic motion
   c) elliptical orbits
   d) parabolic trajectories
   e) no motion, it remains at rest

19. Waves that propagate like a sine wave are called what type of waves?
   a) longitudinal    b) transverse    c) compressional    d) pulse    e) shock

20. Which of the following effects demonstrate the particle nature of light?
   a) piezoelectric    b) Doppler    c) self-inductance
   d) kappa    e) photoelectric

21. Why does light refract when traveling from one transparent medium to another transparent medium?
   a) This results from Rayleigh scattering.
   b) The speed of light changes when traveling from one medium to the other.
   c) The equation of radiative transfer shows that the mean intensity changes at the media interface.
   d) The gluon exchange of the hadrons of each media changes as described in quantum chromodynamics.
   e) Because Dr. Luttermoser said so.
22. Who first interpreted a light wave as a series of spherical wavefronts where each point on the circumference of a given wavefront acts as a point source which generates a new spherical wavefront which propagates outward?
   (a) Huygens  (b) Einstein  (c) Planck  (d) Faraday  (e) Maxwell

23. The act of white light changing into the rainbow of colors as it travels through a prism is called
   (a) dispersion  (b) diffraction  (c) reflection
   (d) interference  (e) impulse

24. Which of the following is used to propagate information through a cable using light?
   a) copper wire  b) galvanometer  (c) fiber optics cable
   d) Lenz's cable  e) none of these

25. An image that forms on the same side of a curved mirror as the object is said to be
   a) erect  b) inverted  c) virtual  (d) real  e) converging

26. If $p \gg R$ for a curved mirror, which of the following is valid?
   a) $q \ll R$  b) $q \gg R$  c) $p = f$  (d) $f = R/2$  e) $p + q = f$

27. Which of the following emits coherent light?
   a) incandescent light bulb  b) halogen light bulb  c) fluorescent lamp
   (d) laser  e) the Sun

28. Reflection off of a smooth surface is known as what kind of reflection?
   a) diffuse  (b) specular  c) glossy  d) matte  e) shiny
29. What is the name of the cells that are sensitive to color in the human eye?
   a) irises     b) cornea     c) rods     d) cones     e) pupils

30. The theoretical best spatial resolution to which an optical system can perform is set by
   a) Maxwell's equations     b) Wein's law     c) Rayleigh's criterion
   d) Huygens' principle     e) Mie's principle
Part C: Problems (40 points total, 10 points each).

31. An ionized deuterium particle \((q = +e, m = 2m_p)\) is traveling in a straight path at a uniform speed of \(6.66 \times 10^6\) m/s in a gravity-free environment. It then abruptly enters a uniform electric field of strength \(5.20 \times 10^4\) N/C pointing in a direction opposite that of the motion of the particle. After a time, this particle leaves the \(E\)-field traveling at a speed of \(2.22 \times 10^3\) m/s in the same direction that it was originally traveling. (a) How much distance did this deuterium particle travel while in the electric field? (b) How much time elapsed while in the \(E\)-field? (Hint: Think of Newton's 2nd Law of Motion and one-dimensional equations of motion while the particle is in the \(E\)-field. Show all work!!!)

\[
\begin{align*}
\text{\(m\)} & \quad \text{\(v_0\)} \\
\text{\(q\)} & \quad \text{\(E = 5.20 \times 10^4\) N/C} \\
\text{\(v_0 = 6.66 \times 10^6\) m/s} & \quad \text{\(\dot{v} = 2.22 \times 10^3\) m/s} \\
\text{\(\chi_0 = 0\)} & \quad \text{\(\chi, t\)} \\
\text{\(t_0 = 0\)} & \quad \text{\(\chi = \_\) \(t\)} \\
\text{\(q = +e = 1.602 \times 10^{-19}\) C} & \quad \text{\(m = 2m_p = 2(1.672 \times 10^{-27}\) kg)} \\
\text{\(= 3.344 \times 10^{-27}\) kg} & \quad \text{\(\) }
\end{align*}
\]

\[a) \quad \begin{align*}
\vec{F} &= \vec{F}_e = \frac{q \cdot \vec{E}}{q} = (-5.20 \times 10^4 \text{ N/C})(1.602 \times 10^{-19} \text{ C}) \\
\vec{F} &= m \vec{a} = m \frac{\vec{v}}{m} = m \frac{\vec{v}}{\vec{v}} = \frac{-8.33 \times 10^{-15} \text{ N}}{3.344 \times 10^{-27} \text{ kg}} = -2.49 \times 10^{-12} \text{ m/s}^2
\end{align*}\]

\[\begin{align*}
\ddot{\chi}^2 &= v_0^2 + 2a(\chi - \chi_0) = v_0^2 + 2a\chi \\
\chi &= \frac{\sqrt{v^2 - v_0^2}}{2a} = \frac{(2.22 \times 10^3 \text{ m/s})^2 - (6.66 \times 10^6 \text{ m/s})^2}{2(-2.49 \times 10^{-12} \text{ m/s}^2)} \\
&= 8.90 \text{ m}
\end{align*}\]

\[b) \quad \begin{align*}
v &= v_0 + a(t - t_0) = v_0 + a t \\
t &= \frac{v - v_0}{a} = \frac{2.22 \times 10^3 \text{ m/s} - 6.66 \times 10^6 \text{ m/s}}{-2.49 \times 10^{-12} \text{ m/s}^2} \\
&= \left\lfloor 2.67 \times 10^{-6} \text{ s} \right\rfloor
\end{align*}\]
32. A steel wire in a piano has a mass $6.973 \times 10^{-3}$ kg and is stretched to produce a tension of 972.0 N. If a key is struck on this wire, a wave of velocity 366.8 m/s is produced. (a) What is the length of this steel wire? (b) What is the wavelength of the fundamental mode of vibration of this wire? (c) What is the fundamental frequency of this wire? (Show all work!!)

\[ m_o = 6.973 \times 10^{-3} \text{ kg}, \quad T = F = 972.0 \text{ N}, \quad v = 366.8 \text{ m/s} \]

\[ a) \quad v = \sqrt{\frac{F}{\mu}}, \quad v^2 = \frac{F}{\mu} \quad \Rightarrow \quad \mu = \frac{F}{v^2} = \frac{972.0\text{ N}}{(366.8 \text{ m/s})^2} \]
\[ = 7.224 \times 10^{-3} \text{ kg/m} \]

\[ \mu = \frac{m_o}{L} \quad \Rightarrow \quad L = \frac{m_o}{\mu} = \frac{6.973 \times 10^{-3} \text{ kg}}{7.224 \times 10^{-3} \text{ kg/m}} \]
\[ = 0.9652 \text{ m} = 96.52 \text{ cm} \]

\[ b) \quad L = \frac{m}{2} \lambda, \quad n=1 \quad \Rightarrow \quad \lambda = 2L = 2(0.9652 \text{ m}) \]
\[ = 1.931 \text{ m} \]

\[ c) \quad v = s \lambda, \quad s = \frac{v}{\lambda} = \frac{366.8 \text{ m/s}}{1.931 \text{ m}} \]
\[ = 190.0 \text{ Hz} \]
33. A thin converging lens has a focal length of 28.4 cm. A 8.66 cm tall object is placed upright 42.7 cm to the left of the lens. (a) Where does the image form and is it virtual or real (give the reason for your answer)? (b) What is the size of the image and is it erect or inverted (give the reason for your answer)? (c) What is the magnification of this system? (Show all work!!)

\[ f = +28.4\text{ cm}, \quad h = +8.66\text{ cm}, \quad p = +42.7\text{ cm} \]

\[ \begin{align*}
\frac{1}{f} & = \frac{1}{p} + \frac{1}{q} \\
\frac{1}{q} & = \frac{1}{p} - \frac{1}{f} = \frac{p - f}{fp} \\
q & = \frac{fp}{p - f} = \frac{(28.4\text{ cm})(42.7\text{ cm})}{42.7\text{ cm} - 28.4\text{ cm}} = +84.8\text{ cm}
\end{align*} \]

Plus sign indicates that the image forms on the other side of the lens and hence is a real image. \((q > 0)\)

\[ M = \frac{h'}{h} = -\frac{q}{p}, \quad h' = -h\left(\frac{q}{p}\right) = -8.66\text{ cm} \cdot \frac{84.8\text{ cm}}{42.7\text{ cm}} = -17.2\text{ cm} \text{ (inverted since } h' < 0) \]

\[ M = \frac{-q}{p} = -\frac{84.8\text{ cm}}{42.7\text{ cm}} = -1.99 \]
34. The resonance spectral line of Na I at 589.6 nm shines on a double slit which forms an interference pattern on a screen with the zeroth-order central fringe marking the $y = 0$ position on the screen. The fifth-order fringe forms at an angle of 0.381° with respect to the line connecting the center point between the slits and the central maximum and is located at $y = 1.06$ cm on the screen. (a) How far is the screen from the two slits? (b) What is the distance between the slits (in mm)? *(Show all work!!!)*

\[
\begin{align*}
\lambda & = 589.2 \text{ nm} \\
m & = 5 \\
\theta_5 & = 0.381^\circ \\
y_{bs5} & = 1.06 \text{ cm}
\end{align*}
\]

**(a)**

\[
y_{bs5} = \frac{\lambda L}{d} m \quad \Rightarrow \quad L = \frac{y_{bs5}}{\tan \theta_5} = \frac{1.06 \text{ cm}}{\tan 0.381^\circ} = 159 \text{ cm} = 1.59 \text{ m}
\]

**(b)**

\[
d = \frac{\lambda L}{y_{bs5}} m \quad \Rightarrow \quad d = \frac{589.2 \times 10^{-9} \text{ m} \times 1.59 \text{ m}}{1.06 \times 10^{-2} \text{ m}} \times 5
\]

\[
= 4.43 \times 10^{-4} \text{ m} \times \frac{1 \text{ mm}}{10^{-3} \text{ m}} = 0.443 \text{ mm}
\]
Extra Credit Problem (5 points each, do this only if you have time).

35. A fully charged 12.3 μF capacitor is connected in series to a 66,400 Ω resistor and a 16.0 V battery. The capacitor begins to discharge. What is the charge on the capacitor after 3.22 seconds? (Show all work!)

\[ C = 12.3 \times 10^{-6} \, \text{F} \]
\[ R = 66,400 \, \Omega \]
\[ \Delta V = 16.0 \, \text{V} \]
\[ q = Q e^{-t/RC} \]
\[ t = 3.22 \, \text{s} \]
\[ C = \frac{Q}{\Delta V}, \quad Q = C \Delta V \]

\[ Q = \left(12.3 \times 10^{-6} \text{F}\right) \times \left(16.0 \, \text{V}\right) \]
\[ = 1.97 \times 10^{-4} \, \text{C} \]

\[ q = \left(1.97 \times 10^{-4} \, \text{C}\right) e^{-3.22 \sqrt{\left(6.64 \times 10^4 \, \Omega\right)\left(12.3 \times 10^{-6} \, \text{F}\right)}} \]
\[ = \left(1.97 \times 10^{-4} \, \text{C}\right) \left(1.94 \times 10^{-2}\right) \approx 3.82 \times 10^{-6} \, \text{C} \]

36. A pencil is 15.2 cm long is projected onto a screen. If the image of this pencil is inverted at a size of -64.6 cm and the separation between the image and the pencil is 4.44 m, what is the focal length of the projection lens? (Show all work!)

\[ h = 15.2 \, \text{cm}, \quad h' = -64.6 \, \text{cm}, \quad p + q = 4.44 \, \text{m} = S' \]
\[ M = \frac{h'}{h} = -\frac{q}{p} = -\frac{-64.6 \, \text{cm}}{15.2 \, \text{cm}} = -4.25 \]
\[ q = S' - p \]
\[ 4.25p + p = S, \quad 5.25p = S, \quad p = \frac{S}{5.25} = \frac{4.44 \, \text{m}}{5.25} \]
\[ q = 4.25p = 4.25(84.6 \, \text{cm}) = 359 \, \text{cm} \]
\[ 0.846 \, \text{m} = 84.6 \, \text{cm} \]
\[ \frac{1}{p} + \frac{1}{q} = \frac{1}{p} + \frac{p}{q} = \frac{q+p}{pq}, \quad f = \frac{qf}{q+p} = \frac{(359 \, \text{cm})(84.6 \, \text{cm})}{359 \, \text{cm} + 84.6 \, \text{cm}} \]
\[ = 68.5 \, \text{cm} \]