Physics 2020-002 Name: KEY

Final (A) – 1 May 2017

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

1. A charged object sits at the center of an evacuated container. At a distance of 72.2 cm from this object, we measure a potential of 3.22 V. What is the charge that resides on the object?

a) 3.21×10^{-19} C b) 1.60×10^{-19} C c) 4.96×10^{-9} C $V = k_e q / r$

(d) 2.59×10^{-10} C e) 3.87×10^{-9} eV

$$q = \frac{Vr}{k_e} = \frac{(3.22\,V)(0.722\,m)}{8.99 \times 10^9\,N\,m^2/C^2} = 2.59 \times 10^{-10}\,C$$

2. A particle has a mass of 7.89×10^{-10} kg and a charge of 4.98×10^{-13} C. If this particle is embedded in a uniform electric field, what would be the strength of this field if the force that the particle experiences is equal to the weight of the particle on the surface of the Earth?

(a) 1.55×10^4 N/C b) 161 N/C c) 6.54×10^{-4} N/C $\rightarrow 1.55 \times 10^4$ N/C

d) 6.44×10^{-6} N/C e) 7.73×10^{-9} N/C

$$F_e = F_g, \quad E = \frac{F_e}{q} = \frac{F_g}{q} = \frac{mg}{q} = \frac{(7.89 \times 10^{-10}\,kg)(9.80\,m/s^2)}{4.98 \times 10^{-13}\,C} =$$

3. A wire with a circular cross-section of 4.66×10^{-3} m^2 is measured to have a resistivity of $8.96 \times 10^{-8}\ \Omega \cdot$ m. How long is the wire if we measure a resistance of $4.56 \times 10^{-3}\ \Omega$ from one end of the wire to the other end?

a) 4.22×10^{-3} m b) 0.488 m c) 6.79 m (d) 237 m e) 6.23 km

$$R = \rho \frac{L}{A}, \quad L = \frac{RA}{\rho} = \frac{(4.56 \times 10^{-3}\,\Omega)(4.66 \times 10^{-3}\,m^2)}{8.96 \times 10^{-8}\,\Omega m} = 237\,m$$

4. An alpha particle ($q = +2e$) is traveling at 20% the speed of light in a direction that is 41.5° with respect to a uniform magnetic field. What is the strength of this magnetic field if this alpha particle feels a magnetic force of 2.00×10^{-8} N?

a) 0.663 T (b) 1.57×10^3 T c) 3.26×10^5 T

d) 1.60×10^6 T e) 3.00×10^8 T

$$F = qvB\sin\theta$$

$$B = \frac{F}{qv\sin\theta} = \frac{2.00 \times 10^{-8}\,N}{(2 \times 1.602 \times 10^{-19}\,C)(0.20 \times 3.00 \times 10^8\,m/s)(\sin 41.5^\circ)}$$

$$= 1570\ T$$

5. The length of the B string on a certain guitar is 62.0 cm. It vibrates at a fundamental frequency 249.0 Hz. What is the speed of the transverse waves on the string?

a) 3.70 m/s b) 4.02 cm/s c) 96.7 cm/s d) 215 m/s e) 309 m/s

$v = f\lambda$, $L = (n/2)\lambda \Rightarrow \lambda = \frac{2L}{n} = \frac{2(0.620\,m)}{1} = 1.24\,m$, $v = (249.0\,s^{-1})(1.24\,m) = 309\,\frac{m}{s}$

6. A light beam traveling in the air hits a glass surface at an angle of 34.8° with respect to the normal. This beam then gets refracted in the glass to an angle 27.2° with respect to the normal. What is the velocity of the light beam in the glass?

a) 3.75×10^8 m/s b) 3.00×10^8 m/s c) 2.40×10^8 m/s d) 1.68×10^8 m/s e) 7.66×10^7 m/s

$\frac{v_i}{\sin\theta_i} = \frac{v_r}{\sin\theta_r}$, $v_i = c$, $n = 1.00$

$v_r = v_i \sin\theta_r / \sin\theta_i = 3.00 \times 10^8\,\frac{m}{s}\,\frac{\sin 27.2^\circ}{\sin 34.8^\circ} = 2.40 \times 10^8\,m/s$

7. The critical angle of a fiber optics cable in air is 42.3°. What is the index of refraction of the material in this cable?

a) 4.00 b) 3.78 c) 2.65 d) 1.98 e) 1.49

$n = \frac{n_{air}}{\sin\theta_c} = \frac{1.00}{\sin 42.3^\circ} = 1.49$

8. A lens forms an inverted 4.55 cm image of a 1.22 cm erect object. If the image forms 62.2 cm from the lens, how far in front of the lens is the object?

a) 1.75 cm b) 16.7 cm c) 22.2 cm d) 32.6 cm e) 232 cm

$M = \frac{h'}{h} = -\frac{q}{p}$, $p = -q\frac{h}{h'} = -(62.2\,cm)\frac{1.22\,cm}{-4.55\,cm} = 16.7\,cm$

9. An optical microscope has a magnification -87.6. The focal length of the objective is 2.66 cm and the focal length of the eyepiece is 1.44 cm. What is the distance between the eyepiece and the objective?

a) 0.153 cm b) 3.83 cm c) 13.4 cm d) 43.8 cm e) 87.6 cm

$M = -\left(\frac{L}{f_o}\right)\left(\frac{25\,cm}{f_e}\right)$, $L = -\frac{M f_o f_e}{25\,cm}$

$L = -\frac{(-87.6)(2.66\,cm)(1.44\,cm)}{25\,cm} = 13.4\,cm$

10. A circular lens has a resolving power of 9.82×10^{-7} rad when viewing light of wavelength 502 nm. What is the diameter of this lens?

a) 16.7 cm b) 21.6 cm c) 30.0 cm d) 42.2 cm e) 62.4 cm

$\theta_m = 1.22\frac{\lambda}{D}$, $D = 1.22\frac{\lambda}{\theta_m} = 1.22\frac{(502\times10^{-9}\,m)}{9.82\times10^{-7}}$

$= 0.624\,m = 62.4\,cm$

Part B: Easy Multiple Choice (20 points total, 1 point each, Circle Best Answer).

11. Who discovered that electric charge is quantized (*i.e.*, multiples of the fundamental charge e)?

a) Ampere b) Watt c) Franklin d) Maxwell e) Millikan

12. Lightning will occur when what happens?

a) The potential between a cloud and the ground exceeds 13.6 V.

b) An occluded front stalls over water.

c) For every Avagodro's number of electrons in the ground, there is an Avagodro's number+1 neutrons in the cloud.

d) The cloud/ground E-field exceeds the dielectric strength of the air.

e) A coronal mass ejection occurs on the Sun.

13. Who discovered the effect of self-inductance?

a) Faraday b) Lenz c) Maxwell d) Ampere e) none of these HENRY

14. Which of the following intensity levels could be heard by humans without suffering damage to the eardrum?

a) -112 dB b) -12.2 dB c) 32 dB d) 150 dB e) 1200 dB

15. We observe 5 different blackbodies and note the type of light that each emit their maximum amount of flux. Of these, which is the hottest?

a) red b) ultraviolet c) green d) infrared e) microwave

16. Which of the following is <u>not</u> a field particle?

a) fermion b) weakon c) gluon d) photon e) graviton

17. The equation $\Phi_E = q/\epsilon_o$ is known as whose law?

a) Maxwell's b) Coulomb's c) Gauss's d) Faraday's e) Ampere's

18. Which of the following is true about plane waves?

a) They are spherical waves that have traveled a long distance.

b) They increase in power as they cover more distance.

c) They increase in power as they travel from a medium with a lower index of refraction to one with a higher index.

d) Their frequency increase as they travel.

e) They do not exist in nature.

19. What does the *principle of causality* demand?

a) The Universe is determinate — for every effect, there is a cause.

b) The Universe is probabilistic — all future happenings are based in probability.

c) Newtonian mechanics does not accurately describe the workings of nature.

d) Boltzmann thermodynamics does not accurately describe the workings of nature.

e) None of these are correct.

20. A bar made of conducting material is connected to a wire forming a circuit. If this bar is free to move along the wire and is embedded in an external magnetic field, moving this bar will produce

a) harmonic motion. b) a constant magnetic flux. c) a motional emf.

d) an equipotential surface. e) an alternating current.

21. Who 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) Einstein b) Planck c) Faraday d) Huygens e) Maxwell

22. Reflection off of a rough surface is known as what kind of reflection?

a) diffuse b) specular c) glossy

d) matte e) shiny

23. The law of refraction also goes by the name of

a) Maxwell's law b) Newton's law c) Coulomb's law

d) Wein's law e) Snell's law

24. Light of different wavelengths being refracted at different angles is an effect known as

a) diffraction b) dispersion c) interference

d) polarization e) scattering

25. The ratio of the speed of light in a vacuum to the speed of light in a material is called the

a) index of refraction b) opacity c) transparency

d) index of reflection e) conductivity

26. A transparent surface with fine parallel lines etched onto it is called a

a) galvanometer b) radiometer c) prism d) lens e) grating

27. Who first demonstrated the interference of light as light waves pass through two pinholes on a screen?

a) Huygens b) Newton c) Lenz d) Young e) Galileo

28. In the equation $d \sin\theta = m\lambda$, m is called the

a) mass b) grating angle c) order number

d) momentum e) polarization

29. *Newton's Rings* result from what principle from optics?

a) diffraction b) reflection c) refraction

d) interference e) polarization

30. Which of the following techniques can be used to polarize light?

a) Heat a gas to very high temperatures.

b) Cool a gas to very low temperatures.

c) Reflect incoherent light off of a smooth surface.

d) Emit the light from an object traveling close to the speed of light.

e) Refract incoherent light through a transparent surface.

Part C: Problems (40 points total, 10 points each).

31. A positively charged oil drop is falling near the surface of the Earth. A thunderstorm is nearby setting up a uniform electric field pointing upward in the area where the drop is located. Starting from rest, it takes this drop 5.66 s to fall 7.24 m. The oil drop has a mass of 6.35×10^{-13} kg and a charge of 7.78×10^{-16} C. (a) At what acceleration is this falling drop? (b) What is the electric force acting on this drop? (c) What is the strength of the electric field? (**Show all work!!!**)

$m = 6.35 \times 10^{-13}$ kg

$y_0 = 7.24$ m

$v_0 = 0$, $t_0 = 0$

$q = 7.78 \times 10^{-16}$ C

$y = 0$, $t = 5.66$ s

(a) $y = y_0 + v_0 (t - t_0) + \frac{1}{2} a (t - t_0)^2$

$0 = 7.24\,m + \frac{1}{2} a t^2$

$a = -\frac{2y_0}{t^2} = -\frac{2(7.24\,m)}{(5.66\,s)^2}$

$= \boxed{-0.452\ m/s^2}$

(b) $\sum F_y = F_e - F_g = ma$

$F_e = F_g + ma = mg + ma$

$= m(g + a)$

$= 6.35 \times 10^{-13}\,kg \left(9.80 \frac{m}{s^2} + [-0.452 \frac{m}{s^2}]\right)$

$= \boxed{5.94 \times 10^{-12}\ N}$

(c) $E = \frac{F_e}{q} = \frac{5.94 \times 10^{-12}\ N}{7.78 \times 10^{-16}\ C} = \boxed{7.63 \times 10^{3} \frac{N}{C}}$

32. A cosmic ray particle has a charge of 5.66×10^{-12} C and a mass of 9.22×10^{-24} kg. This particle is traveling in a circular path which is perpendicular to a uniform magnetic field. Having traveled one Astronomical Unit (AU) in 18.3 minutes at a constant speed to complete its orbit, answer the following questions: (a) At what speed is this particle traveling? (b) What is the radius of its orbit? (c) What is the strength of the magnetic field? (**Show all work!!!**)

$q = 5.66 \times 10^{-12}\ C$, $m = 9.22 \times 10^{-24}\ kg$

$C = 1\ AU \times 1.496 \times 10^{11}\ m/AU = 1.496 \times 10^{11}\ m$

$T = 18.3\ min \times \frac{60\ s}{min} = 1098\ s$

(a) $v = \frac{C}{T} = \frac{1.496 \times 10^{11}\ m}{1098\ s} = \boxed{1.36 \times 10^{8}\ \frac{m}{s}}$

(b) $C = 2\pi r$

$r = \frac{C}{2\pi} = \frac{1.496 \times 10^{11}\ m}{2\pi}$

$= \boxed{2.38 \times 10^{10}\ m}$

(c) $r = \frac{mv}{qB}$, $B = \frac{mv}{qr}$

$B = \frac{(9.22 \times 10^{-24}\ kg)(1.36 \times 10^{8}\ m/s)}{(5.66 \times 10^{-12}\ C)(2.38 \times 10^{10}\ m)}$

$= \boxed{9.32 \times 10^{-15}\ T}$

33. An 4.88 cm tall object sits 28.2 cm to the left of a diverging lens. An upright image is formed by this lens which is 31.3% the size of the object. (a) How far is the image from the lens? (b) What is the focal length of this lens? (c) Which side of the lens is the image on and is the image virtual or real? **Make sure you explain why!** (**Show all work!!!**)

$h = 4.88\ \text{cm}$, $p = 28.2\ \text{cm}$, $f < 0$, $h' = 0.313\,h$

(a) $M = \frac{h'}{h} = -\frac{q}{p}$, $q = -p\frac{h'}{h} = -(28.2\ \text{cm})\frac{0.313\,h}{h}$

$= \boxed{-8.83\ \text{cm}}$

(b) $\frac{1}{p} + \frac{1}{q} = \frac{1}{f} = \frac{q}{qp} + \frac{p}{qp} = \frac{q+p}{qp} = \frac{1}{f}$

$f = \frac{qp}{q+p} = \frac{(-8.83\ \text{cm})(28.2\ \text{cm})}{-8.83\ \text{cm} + 28.2\ \text{cm}}$

$= \boxed{-12.8\ \text{cm}}$

(c) IMAGE IS IN FRONT OF THE LENS AND IS VIRTUAL SINCE $q < 0$.

34. A spectral grating has a resolving power of 18,200 in the second order. (a) What is the spectral resolution of this grating at 5260 Å? (b) How many lines per centimeter are etched on this grating? (c) Let us now shine a light from an emission-line lamp on this grating. Looking at this spectrum on a viewing screen that is 1.67 m from the grating, we see a second-order emission line that is located at an angle of 46.8° from the center line of the grating, what is the wavelength of this emission line in Ångstroms? (**Show all work!!!**)

$R = 18,200$, $m = 2$, $\lambda = 5260\ \text{Å}$

(a) $R = \frac{\lambda}{\Delta\lambda_G}$, $\Delta\lambda_G = \frac{\lambda}{R} = \frac{5260\ \text{Å}}{18,200}$

$$\boxed{\Delta\lambda_G = 0.289\ \text{Å}}$$

(b) $R = N m (\times 1\text{cm})$, $N = \frac{R}{m(\times 1\text{cm})} = \frac{18,200}{2\text{cm}}$

$$\boxed{N = 9100\ \text{lines/cm}}$$

(c) $L = 1.67\ \text{m}$, $m = 2$, $\theta = 46.8°$

$d \sin\theta = m\lambda$, $d = \frac{1}{N} = \frac{1}{9100\ \text{cm}^{-1}} = 1.10 \times 10^{-4}\ \text{cm}$

$\lambda = \frac{d \sin\theta}{m} = \frac{(1.10 \times 10^{-4}\ \text{cm}) \sin 46.8°}{2}$

$\lambda = 4.01 \times 10^{-5}\ \text{cm} \times \frac{1\ \text{Å}}{10^{-8}\ \text{cm}} = \boxed{4010\ \text{Å}}$

Extra Credit Problem (5 points each, do this only if you have time).

35. A 232 Ω resistor and a 636 μF capacitor is hooked in series to a 18.2 V battery and a switch. (a) What is the time constant of this circuit? (b) How much time is needed for this capacitor to reach 55% of its maximum charge once the switch is closed? (**Show all work!**)

$R = 232\,\Omega$, $C = 636 \times 10^{-6}\,F$, $\Delta V = 18.2\,V$

(a) $\tau = RC = (232\,\Omega)(636 \times 10^{-6}\,F) = \boxed{0.148\,s}$

(b) $q = Q(1 - e^{-t/RC})$

$\frac{q}{Q} = 1 - e^{-t/RC}$

$e^{-t/RC} = 1 - \frac{q}{Q}$

$-t/RC = \ln\left(1 - \frac{q}{Q}\right)$

$\rightarrow t = -RC \ln\left(1 - \frac{q}{Q}\right)$

$= -(0.148\,s) \times \ln\left(1 - \frac{0.55Q}{Q}\right)$

$= \boxed{0.118\,s}$

36. A pencil is placed 48.2 cm from a concave mirror. If a real inverted image forms 14.8 cm from the mirror, what is the radius of curvature of the mirror? (**Show all work!**)

$p = 48.2\,cm$

$q = +14.8\,cm$

$\frac{1}{p} + \frac{1}{q} = \frac{2}{R} = \frac{q}{pq} + \frac{p}{pq}$

$\frac{2}{R} = \frac{q+p}{pq}$

$\frac{R}{2} = \frac{pq}{q+p}$

$R = \frac{2pq}{q+p} = \frac{2(48.2\,cm)(14.8\,cm)}{14.8\,cm + 48.2\,cm}$

$= \boxed{22.6\,cm}$