Harvard Undergraduate Science Olympiad India
2024 Open Round
Physics (9th-10th Grade) Exam

Recall: All five fields (Maths, Biology, Chemistry, Physics, Earth Science) will be provided to you in one singular exam. Each section (corresponding to one field) is designed to take 20 minutes. Your performance on all 5 sections will be considered for your final score. Each section is weighed equally.

Format of Physics Section: The Physics section will contain only single-select multiple choice questions with 5 answer choices each. The section will have 40 multiple choice questions.

Scoring: Each correct answer will give you 1 point. You will lose 0.25 points for an incorrect answer. You will receive 0 points for a question left blank.

Allowed Materials:
You must bring:

- #2 pencil
- Eraser

You are allowed:

- Non-programmable, non-graphing calculator
- Wrist-watch (not a smart watch)

You may not bring

- Smart watch
- Books or notes
- Electronic devices

1. Which of the following effects most directly explains why the sky is blue?

    a. Atmospheric Escape
    b. Photoelectric Effect
    c. Huygens' Principle
    d. Mie Scattering
    e. Rayleigh Scattering

2. $\frac{M+m}{m}\sqrt{2gl(1-cos\theta)}$A block of wood is dangling from a rope of length *l*. A bullet with mass *m* is shot into the block of wood, causing it to swing up by a certain angle θ. The combined mass of the bullet and the block is *M*. Given these parameters, what is the initial speed of the bullet, assuming the initial path of the bullet is perpendicular to the pendulum?

    a. $\frac{M}{m}\sqrt{2gl}$
    b. $\sqrt{2gl(1-sin\theta)}$
    c. $\frac{M+m}{m}\sqrt{2gl(1-sin\theta)}$
    d. $\frac{M}{m}\sqrt{2gl(1-cos\theta)}$
    e. $\frac{M+m}{m}\sqrt{2gl(1-cos\theta)}$

3. A positron (a particle with the mass of an electron, and the charge of a proton) inside a region with a magnetic field is traveling in a circle, with a radius of 8.0 microns, and a speed of 3000 m/s. What is the strength of the magnetic field?

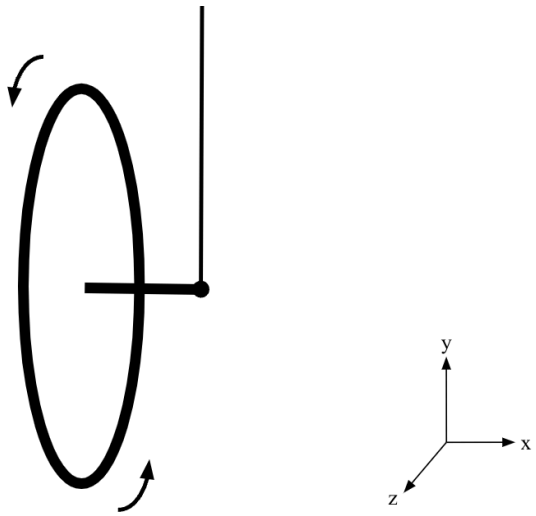
    a. $2.1*10^{-3}$ T
    b. $2.4*10^{-3}$ T
    c. $2.7*10^{-2}$ T
    d. $3.5*10^{-2}$ T
    e. $6.1*10^{-2}$ T

4. A metal ball with a radius of 15 cm has 14.0 μC of charge on it. What is the value of the electric potential at a point 12 meters away from the center of the ball? Assume that the electric potential is 0 at an infinite distance away.

    a. 0.00 V
    b. 10490 V
    c. 17980 V
    d. 36000 V
    e. 179800 V

5. For the same setup given in question 4, what is the electric potential inside the ball, at a point 2 cm away from the center?

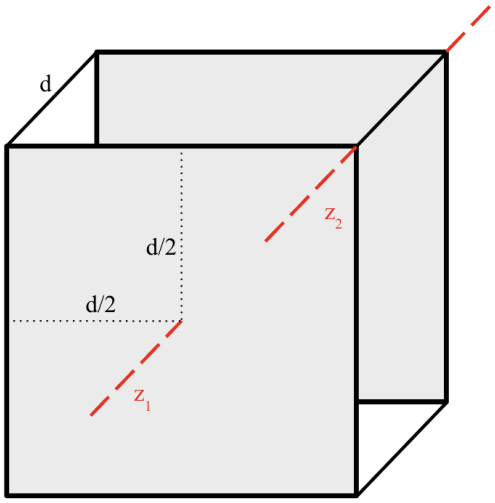
a. 57.54 V
b. 719200 V
c. 839100 V
d. 7192000 V
e. 89900000 V



(Diagram for Problem 5)

6. Describe the motion of the wheel and axle after the moment shown in the diagram

a. Precession of the angular momentum vector around the x axis
b. Precession of the angular momentum vector around the y axis
c. Precession of the angular momentum vector around the z axis
d. Swinging like a pendulum in the x-y plane
e. Swinging like a pendulum in the x-z plane



(Diagram for Problems 35-36)

7. A cube with side lengths d is constructed out of two metal planets, each with mass *M*, connected by 4 rods, each with mass of *m*. What is the moment of inertia about the z_1 axis?

   a. $\frac{Md^2}{3} + 2md^2$
   b. $\frac{Md^2}{3} + 4md^2$
   c. $\frac{Md^2}{6} + 2md^2$
   d. $\frac{Md^2}{6} + 4md^2$
   e. $\frac{Md^2}{12} + md^2$

8. For the same cube, what is the moment of inertia about the z_2 axis?

   a. $\frac{Md^2}{3} + md^2$
   b. $\frac{Md^2}{3} + 4md^2$
   c. $\frac{4Md^2}{3} + md^2$
   d. $\frac{4Md^2}{3} + 2md^2$
   e. $\frac{4Md^2}{3} + 4md^2$

9. An AC circuit has a 4Ω resistor, a 7mH inductor, and 0.25 mF capacitor are connected in series. If the total impedance of the circuit is 5.0Ω, what is the oscillation frequency of the voltage source?

   a. 0.16 Hz
   b. 35 Hz

c. 160 Hz
d. 710 Hz
e. 11000 Hz

10. You construct a frictionless ramp with an angle θ. You place a block of mass M on the ramp, and then place a hollow ball with mass m and radius r on top of the block. There is a coefficient of friction of μ between the block and the ball. Assuming that the ball doesn't slip, what is the acceleration of the ball with respect to the ramp?

a. $\frac{13g\sin\theta}{5}$
b. $\frac{g\sin\theta}{5}(5 - \frac{2m}{M})$
c. $\frac{g\sin\theta}{5}(8 - \frac{2m}{M})$
d. $\frac{g\sin\theta}{7}(12 - \frac{2m}{M})$
e. $\frac{g\sin\theta}{7}(12 + \frac{m}{M})$

11. You purchase a large metal ball for fun one day. You place a charge of 7μC on the ball, also for fun. The ball has a radius of 0.5 meters. What is the value of the electric field immediately outside the surface of the ball?

a. $2.52*10^5 \frac{N}{C}$
b. $1.26*10^5 \frac{N}{C}$
c. $2.52*10^3 \frac{N}{C}$
d. $1.76*10^0 \frac{N}{C}$
e. $1.96*10^{-10} \frac{N}{C}$

12. You are in a circular room with a radius of R, leaning against the wall. There is a coefficient of friction of μ between you and the wall. The room starts spinning, and the floor drops out from under you. What is the minimum angular velocity necessary to ensure that you don't slide down the wall?

a. $\mu^2\sqrt{\frac{g}{R}}$
b. $\sqrt{\frac{\mu g}{R}}$
c. $\sqrt{\frac{g}{\mu R}}$
d. $\sqrt{\frac{(\mu+1)g}{R}}$

e. $\sqrt{\frac{g}{(1+\sqrt{\mu})R}}$

13. A box of mass *M* and initial rightward velocity of *v* collides elastically with a box of mass *2M*. The *2M* box then collides elastically with a box of mass *3M*. What is the velocity of all three boxes after that last collision?

a. M: $\frac{v}{6}$, $2M$: $\frac{v}{6}$, $3M$: $\frac{v}{6}$
b. M: $\frac{v}{6}$, $2M$: $\frac{v}{3}$, $3M$: $\frac{v}{2}$
c. M: $\frac{-v}{3}$, $2M$: $\frac{-2v}{15}$, $3M$: $\frac{3v}{15}$
d. M: $\frac{-v}{3}$, $2M$: $\frac{-2v}{15}$, $3M$: $\frac{8v}{15}$
e. M: $\frac{-v}{6}$, $2M$: $\frac{-7v}{30}$, $3M$: $\frac{49v}{90}$

14. Between two large metal plates, there exists a constant electric field of $5.5\ \frac{N}{C}$. Neglecting fringe behavior, if the two plates are separated by 0.5 cm, what is the electric potential difference between the two plates?

a. 0.028 V
b. 1.100 V
c. 2.750 V
d. 10.10 V
e. 1100. V

15. An ideal gas is kept in a piston. Initially, the volume of the gas is 0.2 m^3, and the pressure is measured to be 2,000 N/m^2. The gas then expands isothermally to a volume of 0.7 m^3. How much work is done *by* the gas?

a. 0.0 J
b. 280.1 J
c. 501.1 J
d. 2505.5 J
e. 2857.1 J

16. Which two equations primarily explain the ability of light to self-propagate through a vacuum?

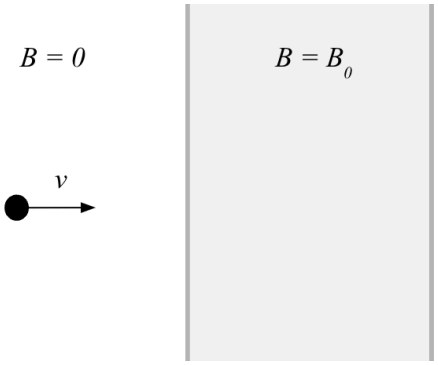
a. Gauss's Law and Gauss's Law for Magnetism
b. Gauss's Law and Ampere-Maxwell Law
c. Faraday's Law and Snell's Law
d. Faraday's Law and Ampere-Maxwell Law
e. Malus's Law and Gauss's Law for Magnetism

17. A car is racing with speed v on a circular track with a radius of R. There is a coefficient of friction of μ between the car and the track. The car then hits the brakes. At that point, what is the maximum possible magnitude of acceleration? Assume no slipping at any time.

a. μg
b. $\mu g - \frac{v^2}{R}$
c. $\sqrt{g^2 - \mu \frac{v^4}{R^2}}$
d. $\sqrt{\mu^2 g^2 - \frac{v^4}{R^2}}$
e. $g\sqrt{\mu^2 + \frac{gR}{v^2}}$

18. A spaceship is traveling at $0.9c$. You time how long it takes for the spaceship to travel in a straight line between the Sun and Jupiter, separated by about $7.5*10^{11}$ meters. How long does the journey take from the point of view of your friend on the spaceship?

a. 533 seconds
b. 1,211 seconds
c. 2,499 seconds
d. 2,777 seconds
e. 6,373 seconds



(Diagram for Problems 19-20)

19. A ball with mass m and charge q is heading towards a region with a magnetic field with a speed v. The magnetic field is pointing out of the page. How much work is done on the particle before it exits the region with the magnetic field?

a. 0
b. $2mv^2$

c. $\frac{kq^3B_0}{mv}$

d. $\frac{m^3v^3}{2\mu_0 q^3 B_0}$

e. $\frac{\pi m}{\varepsilon_0 \mu_0}$

20. If the magnetic field region has a horizontal width of D, what is the necessary value of *v* to ensure that the ball will leave the magnetic region to the right?

a. 0

b. $\frac{kq}{B_0 D^2}$

c. $\frac{qB_0 D}{m}$

d. $\frac{2\pi qB_0 D}{m}$

e. $\frac{\pi\mu_0 q^3 B_0}{2m^2}$

21. A planet has an density distribution given by the function $\rho(r) = ar$. The planet has a radius of *R*, and a surface gravity of *g*. Inside of the planet, what distance from the center will have a gravitational acceleration of g/2?

a. $r = \frac{3R}{4}$

b. $r = \frac{\sqrt{2}R}{2}$

c. $r = \frac{\sqrt{3}R}{R}$

d. $r = \frac{R}{4}$

e. $r = \frac{R}{8}$

22. You take a filled balloon to an exoplanet (g = 1.52 m/s^2), and you want to determine the atmospheric pressure. While keeping the temperature of the gas constant, you submerge the balloon in the planet's methane ocean (ρ = 422.36 kg/m^3). You submerge the balloon by 560 meters before the balloon's volume has reduced by 25%. What is the surface atmospheric pressure?

a. 8.988*10^4 Pa

b. 2.696*10^5 Pa

c. 3.595*10^5 Pa

d. 4.668*10^5 Pa

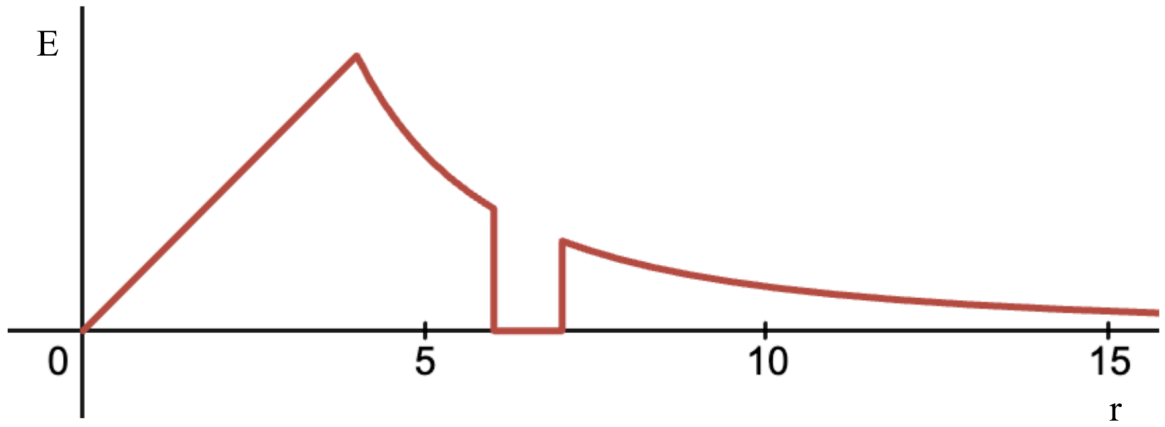
e. 1.079*10^6 Pa

23. A photon of green light has a wavelength of 520 nm. How many moles of photons do you need to have 7 kJ of energy?

    a. $3.039*10^{-2}$ mol
    b. $2.127*10^{-1}$ mol
    c. $2.303*10^{5}$ mol
    d. $3.039*10^{7}$ mol
    e. $3.372*10^{10}$ mol

24. A 7.0L piston is filled with 0.6 moles of an ideal gas, kept at 2.1 atm. The gas is then heated, and the piston is allowed to expand such that the temperature of the gas remains constant. If 270 J of heat is added to the system, what is the change in entropy of the system?

    a. 0.104 J/K
    b. 0.904 J/K
    c. 8.391 J/K
    d. 13.500 J/K
    e. 91.580 J/K



(Diagram for Problems 25 and 26)

25. You are given the above graph of electric field over radial distance for a spherically symmetrical set-up. Which of the following set-ups would have such an electric field graph?

    a. Two neutral thick metal shells, separated by an empty layer
    b. A charged metal sphere, surrounded by an empty layer, and then a neutral thick metal shell
    c. A plastic ball with charge distributed at the center, surrounded by an empty layer, and then a neutral thick metal shell

d. A plastic ball with uniform charge distribution, surrounded by an empty layer, and then a thick metal shell
e. A plastic ball with uniform charge distribution, surrounded by a charged metal layer, and then a neutral metal shell

26. If the point $r = \infty$ has an electric potential of 0, where is the electric potential at its highest?

a. $r = 0$
b. $r = 4$
c. $r = 6$
d. $r = 7$
e. $r = \infty$

27. You have taken a job as a civil engineer for the city. A network of pipes takes water from the water treatment plant in the valley (h=185) to the city (h=270). Given that the density of air is 1.29 kg/m^3, and the density of water is 997 kg/m^3, you can ignore the pressure difference for now. If water is measured to be moving at 60 m/s at the plant, how fast is it moving once it reaches the city?

a. 5.099 m/s
b. 40.82 m/s
c. 43.97 m/s
d. 72.75 m/s
e. 81.87 m/s

28. Continuing from problem 27, suppose that your city is not on Earth, but on an exoplanet with an atmospheric density near the city of 103 kg/m^3, and a surface gravity of g = 7.33 m/s^2. If everything else remains the same, what is the speed of the water at the city?

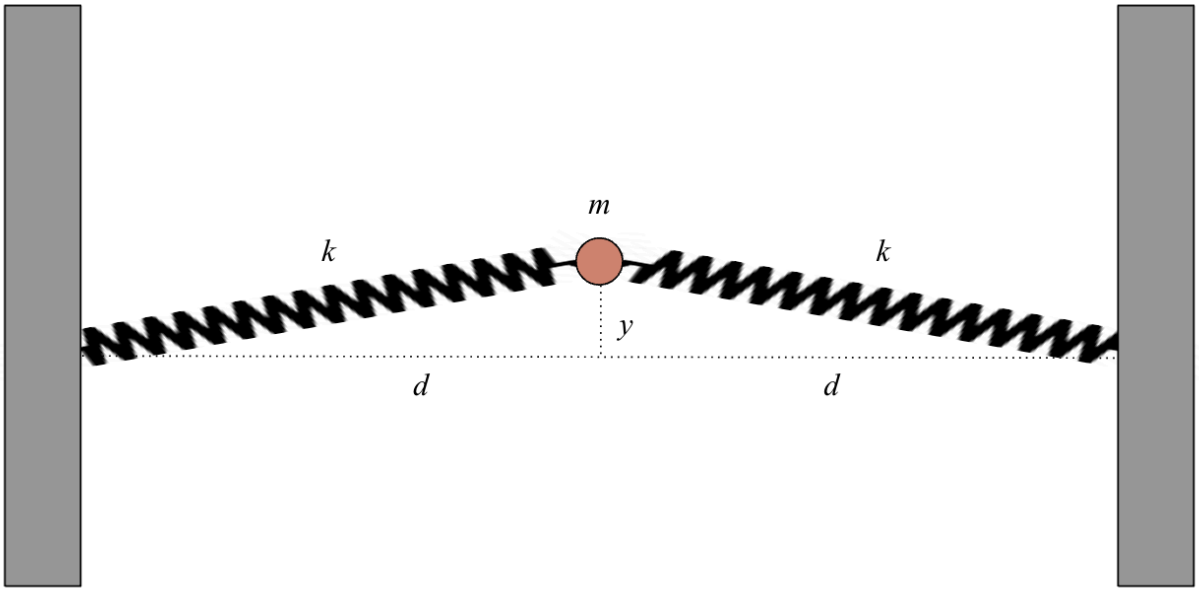
a. 7.122 m/s
b. 34.18 m/s
c. 49.83 m/s
d. 68.68 m/s
e. 120.1 m/s

29. An electron travels in a circle in a region with a magnetic field. A tiny metal ball with a mass of 0.2 nanograms also travels in a circle in the same region. At *t=0*, the electron and ball start in the same spot, with velocities pointing in the same direction. What is the smallest value of charge that the ball can have such that after the electron travels one full loop, the ball is also back at the same point?

a. $1.602*10^{-19}$ C
b. $8.015*10^{-10}$ C
c. $4.414*10^{-5}$ C

d. $3.513*10^{1}$ C

e. It depends on the value of the magnetic field



30. You have a ball connected to two springs of spring constant k with rest length d. You displace the ball by a very small amount y. Neglecting gravity, which of the following equations of motion describes the scenario above?

a. $-2ky = m\frac{d^2y}{dt^2}$

b. $-\frac{2ky^2}{d} = m\frac{d^2y}{dt^2}$

c. $-ky(2 + \frac{y^2}{d^2}) = m\frac{d^2y}{dt^2}$

d. $-\frac{ky^3}{2d^2} = m\frac{d^2y}{dt^2}$

e. $-\frac{ky^3}{d^2} = m\frac{d^2y}{dt^2}$

31. You are standing a distance of 2.5 meters away from a concave mirror with a focal length of 0.5 meters. What is the distance between the image created, and the mirror?

a. 0.200 m

b. 0.625 m

c. 2.550 m

d. 5.000 m

e. 12.50 m

32. You are an astronaut exploring an exoplanet, with mass M and radius R. Your rocket has a dry mass of m, and will have an exhaust velocity of v_e. In terms of mass, how much fuel do you need to escape the planet's gravity?

a. $\sqrt{\frac{2GM^2m}{Rv_e^2}}$

b. $\sqrt{\frac{2GMm^2}{Rv_e^2}}$

c. $me^{\sqrt{\frac{2GM}{Rv_e^2}}}$

d. $m(e^{\sqrt{\frac{2GM}{Rv_e^2}}} + 1)$

e. $m(e^{\sqrt{\frac{2GM}{Rv_e^2}}} - 1)$

33. Continuing from problem 32, you speed up to a velocity of c/5, flying away from the planet. You turn on your computer to look at the signal coming from a probe on the surface of the planet. Your computer gives a frequency of f. You then remember that you haven't considered the Doppler effect into account. Adjusting for this, what is the real frequency emitted by the probe?

a. $5f$

b. $\frac{\sqrt{6}}{2}f$

c. $\frac{\sqrt{6}}{3}f$

d. $\frac{1}{2}f$

e. $\frac{\sqrt{6}}{6}f$

34. Continuing from Problem 32 and 33, as you head home from your exoplanet expedition, you notice a buildup of heat. Your machinery is producing thermal energy at a constant rate of 9.3 million watts. Your rocket is roughly shaped like a cylinder with a radius of 20 meters, and a length of 120 meters. If your rocket's surface has an emissivity of 0.2, what will the final temperature of the rocket be?

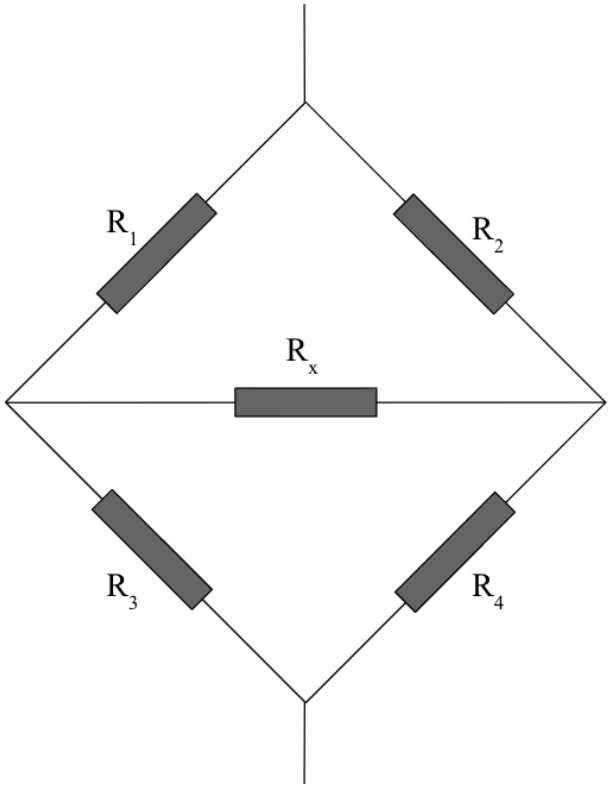
a. 310.7 K

b. 322.9 K

c. 464.7 K

d. 482.9 K

e. 764.6 K



(For Problem 35)

35. Shown above is a Wheatstone Bridge. What is the expression for R_1 in terms of the other resistances such that when the circuit is connected to a voltage, there is no voltage drop across the R_x resistor?

a. $R_2 + R_4 - R_3$

b. $\frac{R_3 R_4}{R_2}$

c. $\frac{R_2 R_3}{R_4}$

d. $\frac{R_3}{R_x}(R_2 + R_4)$

e. $R_x^{\,2}(\frac{1}{R_3} + \frac{1}{R_2+R_4})$

36. A situation is created such that for a Gaussian Sphere with a radius of R, the electric field is given by the equation $E = kcos^2(\theta)sin(\frac{\phi}{2})$, where θ is the polar angle (think latitude) and ϕ is the azimuthal angle (think longitude). What is the total charge contained in this Gaussian Sphere?

a. $\varepsilon_0 kR^2$

b. $4\pi\varepsilon_0 kR^2$

c. $4\pi^2\varepsilon_0 kR^2$

d. $(\pi^2 + 4)\varepsilon_0 kR^2$

e. 0

37. A spherical capacitor is constructed of two spherical concentric plates, one of a radius of *r* and the other with a radius of *2r.* A voltage of *V* is placed on the capacitor, and the capacitor is then connected to a non-charged parallel plate capacitor, with plate area r^2, and plate separation *r/2*. What is the final charge on the spherical capacitor?

a. $2\varepsilon_0 rV$

b. $8\pi\varepsilon_0 rV$

c. $\frac{4\pi\varepsilon_0 rV}{1-4\pi}$

d. $\frac{8\pi\varepsilon_0 rV}{1+4\pi}$

e. $\frac{32\pi^2\varepsilon_0 rV}{1+4\pi}$

38. After a successful expedition, you are standing exactly at the North Pole (for the sake of this question, assume that the Geographic North Pole and Magnetic North Pole are the same). You throw a charged metal ball straight forward. If the strength of the magnetic field is 60μT, what does the charge to mass ratio need to be to ensure that the magnetic force and Coriolis force cancel out?

a. -2.424 C/kg
b. -1.212 C/kg
c. 1.212 C/kg
d. 2.424 C/kg
e. It is not possible to balance the two forces

39. What is the name of the effect that involves the splitting of spectral lines due to the presence of a static magnetic field?

a. Zeeman Effect
b. Rowland Effect
c. Faraday Effect
d. Boltzmann Effect
e. Einstein Effect

40. What is the rest energy of an electron?

a. 0.170 MeV
b. 0.511 MeV

c. 1.00 MeV
d. 1.67 MeV
e. 9.11 MeV

Important Constants

Universal Gravitational Constant:	$6.67*10^{-11}$ Nm^2/kg^2
Speed of Light:	$3.00*10^{8}$ m/s
Mass of an electron:	$9.11*10^{-31}$ kg
Charge of an electron:	$-1.60*10^{-19}$ C
Permittivity of Free Space:	$8.85*10^{-12}$ C/Nm^2
Stefan Boltzmann Constant:	$5.67*10^{-8}$ W/m^2K^4