AP Physics 2

45 Practice Problems

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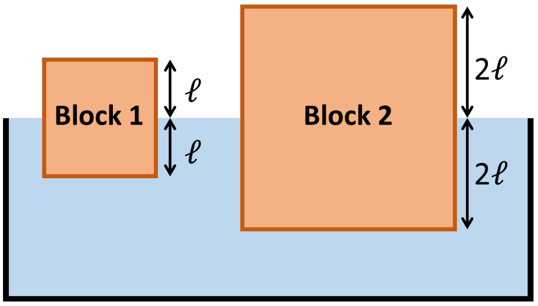
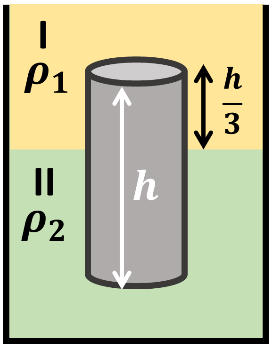
1. Two cubes of different sizes and masses float in a tray of water. Each block is half submerged, as shown in the figure. Water has a density of 1000 kg/m^3. What can be concluded about the densities of the two blocks?



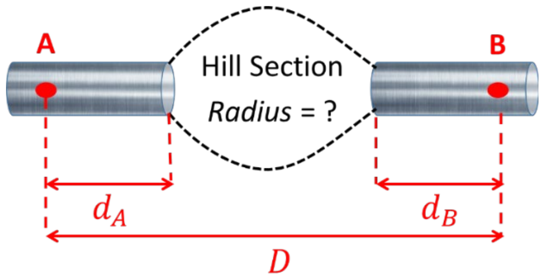
(A) The density of block 1 is greater than the density of block 2.
(B) The density of block 2 is greater than the density of block 1.
(C) Both blocks have density equal to 500 kg/m^3.
(D) Both blocks have the same density, but the density cannot be determined without the value of ℓ.

2. A cylinder is in equilibrium inside a container filled with two liquids I and II, as shown. The densities of liquids I and II are ρ_1 and ρ_2, respectively. The density of the material that constitutes the cylinder equals:



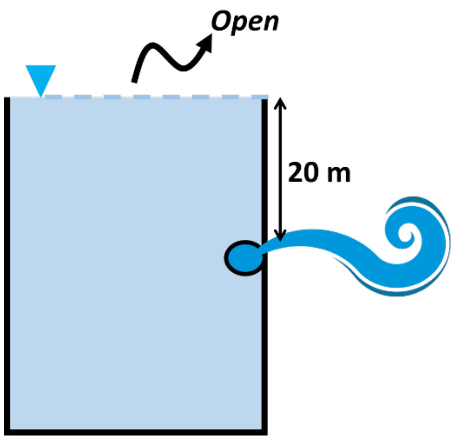
(A) $\dfrac{\rho_1+\rho_2}{3}$
(B) $\dfrac{2\rho_1+\rho_2}{3}$
(C) $\dfrac{\rho_1+2\rho_2}{3}$
(D) $\dfrac{3\rho_1+2\rho_2}{3}$

3. The following figure shows two sections of an old pipe system that runs through a hill, with distances $d_A = d_B = 30$ m and $D = 100$ m. On each side of the hill, the pipe radius is 3.0 cm. However, the radius of the pipe inside the hill is no longer known. To determine it, hydraulic engineers first establish that water flows through the left and right sections at 2 m/s. Then they release a dye in the water at point A and find that it takes 140 sec to reach point B. What is the average radius of the pipe within the hill?



(A) 4.5 cm
(B) 5.0 cm
(C) 6.0 cm
(D) 7.0 cm

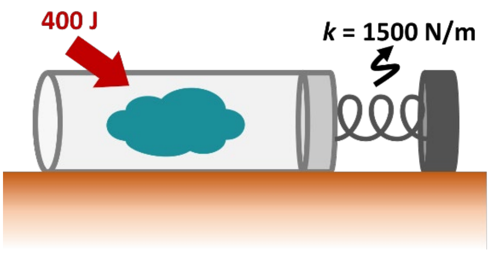
4. A large storage tank, open at the top and filled with water, develops a small hole in its side at a point 20 m below the water level. The rate of flow from the leak is found to be 5×10^{-3} m^3/min. The diameter of the hole is most nearly:



(A) 4.1 mm
(B) 5.5 mm
(C) 7.3 mm
(D) 9.1 mm

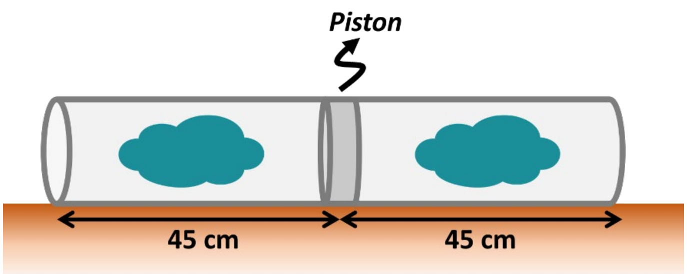
5. A monoatomic gas is heated and expanded in isobaric fashion. What percentage of the heat administered to the gas becomes internal energy?
(A) 40%
(B) 60%
(C) 80%
(D) 100%

6. The system shown below contains a cylinder with an ideal gas. The movable piston is attached to an initially undeformed spring with stiffness equal to 1500 N/m. As 400 J of heat is transferred to the gas, the cylinder expands and the movable piston is deformed in such a way that the spring ends up compressed by 40 cm. In this process, what was the change in the internal energy of the gas?



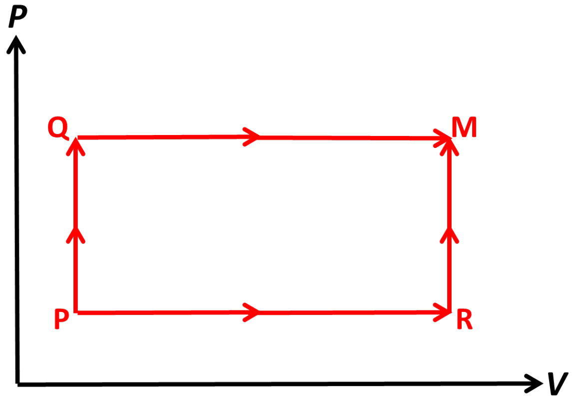
(A) 280 J
(B) 310 J
(C) 340 J
(D) 370 J

7. The figure shows a slender, closed tube that contains air in normal conditions. The tube contains a movable piston, as shown. When the tube is placed in a vertical position, the piston is lowered by x centimeters. If P_1 and P_2 are the new pressures in the upper and lower parts, respectively, in such a way that $P_2 = 2P_1$ and the process was isothermal, what is the value of x?



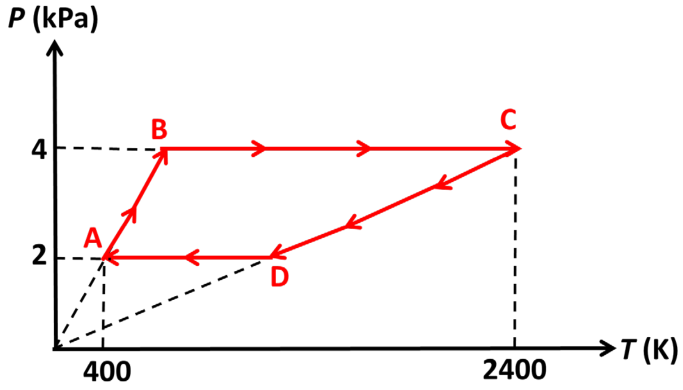
(A) 5 cm
(B) 10 cm
(C) 15 cm
(D) 20 cm

8[1]. Refer to the following graph. When an ideal gas undergoes process PQM, it absorbs 20 kJ of heat and does an amount of work equal to 8 kJ. How much heat does the system absorb along process PRM, if in this case it does a work of 3 kJ?



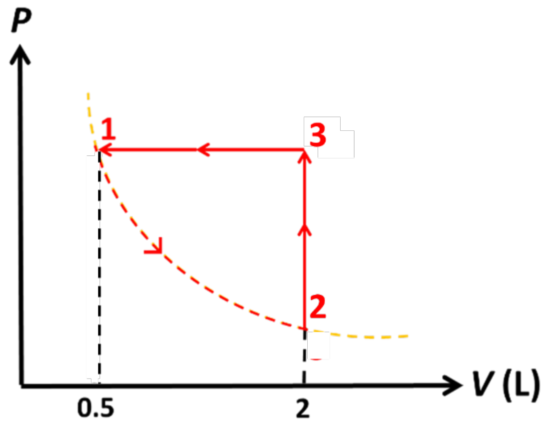
(A) 3 kJ
(B) 12 kJ
(C) 15 kJ
(D) 18 kJ

9. The graph shows the variation of pressure and temperature in a thermodynamic cycle $A \to B \to C \to D$ followed by an ideal gas. In A, the gas had a volume of 3 m^3. What is the work done by the gas in the cycle?



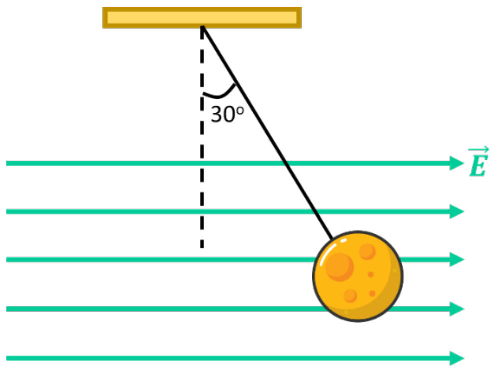
(A) 6 kJ
(B) 9 kJ
(C) 12 kJ
(D) 15 kJ

10. An ideal gas is subjected to the thermodynamic cycle shown. What is the ratio of the root-mean-square speed of the gas molecules in state (3) to that of the gas molecules in state (1)?



(A) 2
(B) 3
(C) 4
(D) 8

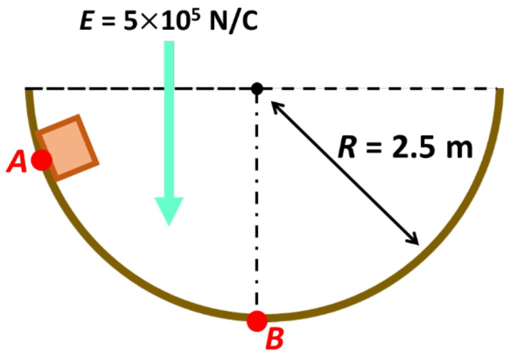
11. A small sphere with positive charge equal to 50 μC and weight equal to 0.84 N is suspended by a string that makes an angle of 30° with the vertical, as shown. The sphere is immersed in an uniform, horizontal electrical field. If the system is in equilibrium, the intensity of the field is, most nearly:



(A) 1.6×10^3 N/C
(B) 3.0×10^3 N/C
(C) 6.3×10^3 N/C
(D) 9.7×10^3 N/C

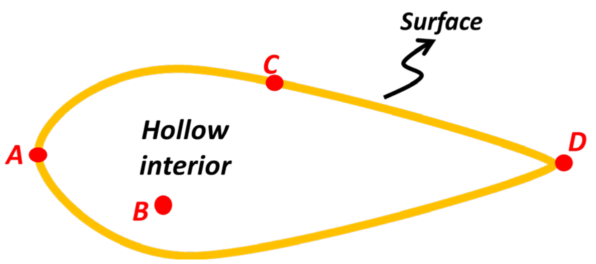
[1] *Problems 8, 9 and 10 involve thermodynamic cycle analysis. This topic is not included in the AP Physics 2 syllabus, but knowing how to interpret simple cycles shows that you have a good grasp of the first law and the ideal gas law, which are part of the syllabus. Feel free to skip to Problem 11 if you're not interested in these subjects.*

12. A 5-kg block with charge q = 30 μC is released from point A, as shown. The ramp has the form of a semicircle of radius R = 2.5 m, and the region is under the effect of a 5×10^5-N/C downward electric field. Knowing that the block reaches point B with a velocity of 3 m/s, what is the reaction at B? Neglect friction.



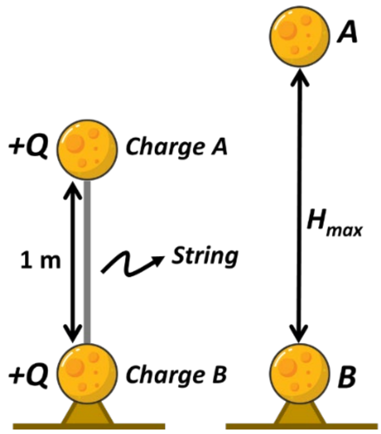
(A) 55 N
(B) 68 N
(C) 74 N
(D) 82 N

13. The following figure shows a hollow electrified conductor in electrostatic equilibrium. Regarding this system and points A to D, which of the following is **false**?



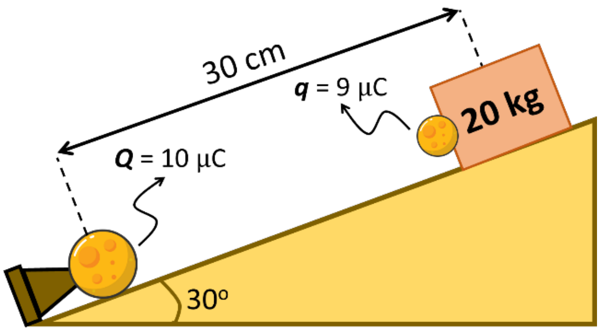
(A) The electrical potential is the same at points A, C and D.
(B) The resultant electric field intensity at point B equals zero.
(C) The intensity of the electrical field is greater at point A than at point D.
(D) The electrical potential at point B is different from zero.

14. The system illustrated below consists of two charges Q linked by a vertical string. Charge A has a mass of 200 g and charge B is attached to the ground by a fixed support. In the conditions shown, the system is in equilibrium and the tension in the string is 8 N. If the string is suddenly cut, what will be the maximum height reached by charge A?



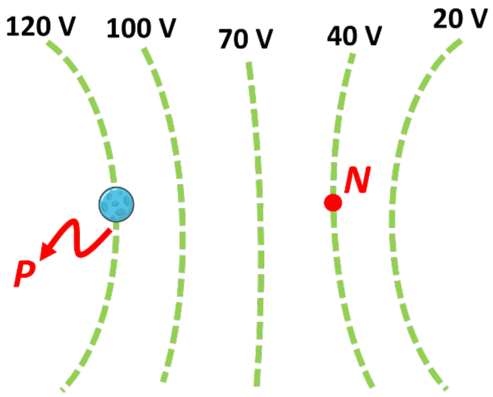
(A) 2 m
(B) 3 m
(C) 4 m
(D) 5 m

15. A block with mass equal to 20 kg is attached to a point charge q = 9 μC. The block is released from rest on an inclined plane with a fixed charge Q = 10 μC at the bottom, as shown. What is the maximum kinetic energy attained by the block?



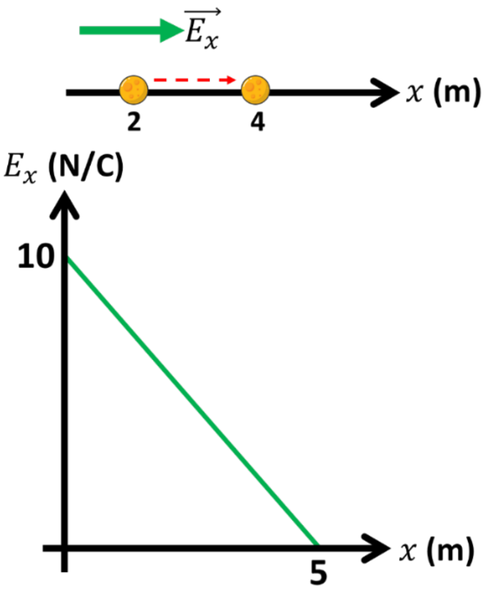
(A) 13.1 J
(B) 13.7 J
(C) 14.3 J
(D) 14.9 J

16. A particle of 4-g mass and charge equal to −2 mC is driven by an external force from point P to point N, as shown. Noting that the particle was initially at rest at point P, and that the work done by the external force was 0.36 J, what was the speed of the particle when it reached point N?



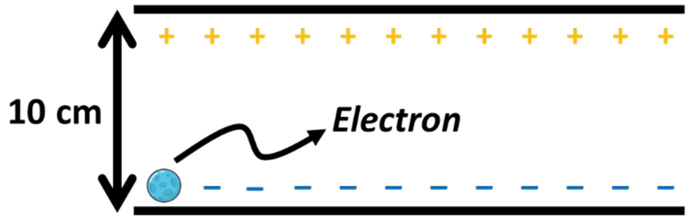
(A) 5 m/s
(B) 10 m/s
(C) 12 m/s
(D) 15 m/s

17. The intensity of an electric field in a certain region varies as a function of horizontal coordinate x as shown the following graph. If a small 2-g sphere electrified with 8 mC is released in position x = 2 m, what will be its velocity at x = 4 m? Neglect gravity.



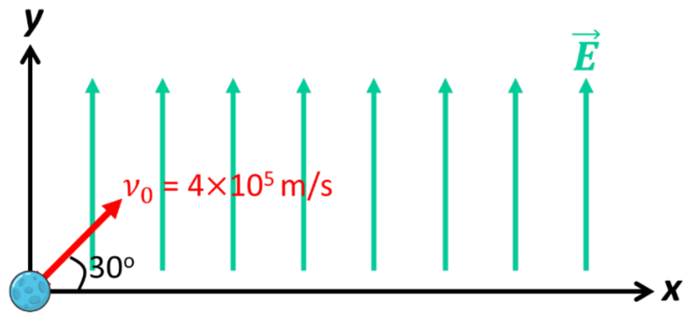
(A) 6 m/s
(B) 8 m/s
(C) 10 m/s
(D) 12 m/s

18. The figure shows two horizontal films with opposite charges, separated by a distance of 10 cm. An electron on the negative film leaves rest and reaches the opposite film in 50 ns (nanoseconds). What is the intensity of the uniform electrical field between the two films? Neglect gravity.



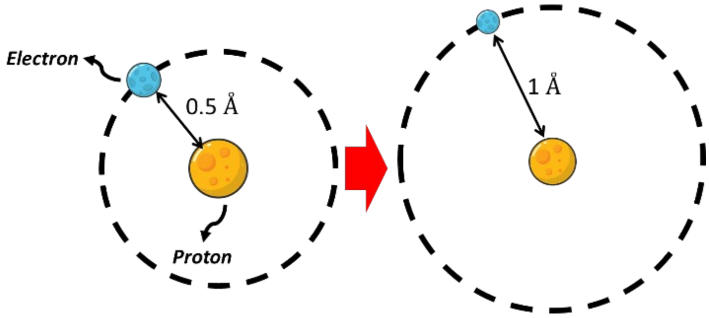
(A) 150 V/m
(B) 300 V/m
(C) 450 V/m
(D) 600 V/m

19. On instant t = 0, an electron is projected from an angle of 30° relatively to the x-axis with a speed v_0 = 4×10^5 m/s, as shown. Knowing that the electron moves in a constant electric field E = 100 N/C, what is the time required for the electron to cross the x-axis a second time?



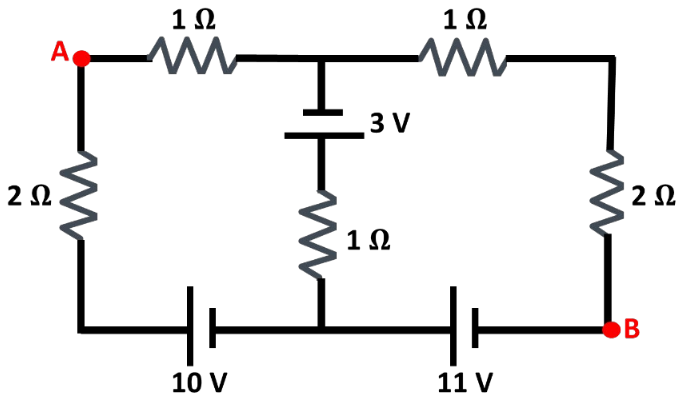
(A) 8 ns
(B) 13 ns
(C) 23 ns
(D) 40 ns

20. Suppose an electron rotates around a proton in an orbit of radius equal to 0.5 Å. How much energy should be added to the system to increase the orbit radius to 1 Å?



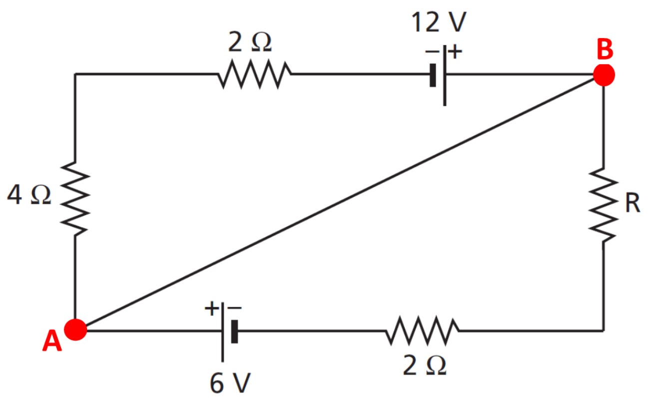
(A) 10×10^{-19} J
(B) 11.52×10^{-19} J
(C) 12.52×10^{-19} J
(D) 13.1×10^{-19} J

21. In the circuit shown in the figure, what is the potential difference between points A and B?



(A) 7 V
(B) 9 V
(C) 11 V
(D) 13 V

Problems 22 and 23 refer to the following figure.



22. The circuit is powered by two batteries. What is the value of the current in wire AB if resistance R equals 10 Ω?
(A) 1.0 A
(B) 1.5 A
(C) 2.0 A
(D) 2.5 A

23. What should be the value of R for there to be no current across AB?
(A) 1 Ω
(B) 2 Ω
(C) 3 Ω
(D) 4 Ω

24. Figure 1 shows a parallel-plate capacitor with vacuum as the medium separating the two plates; in this case, the capacitance of the device is C_0. Figure 2 shows the same system with a small modification: a dielectric plate of thickness $D/4$ and dielectric constant K is placed between the two plates. In this case, the capacitance of the device is C_1. What is the value of ratio C_1/C_0?

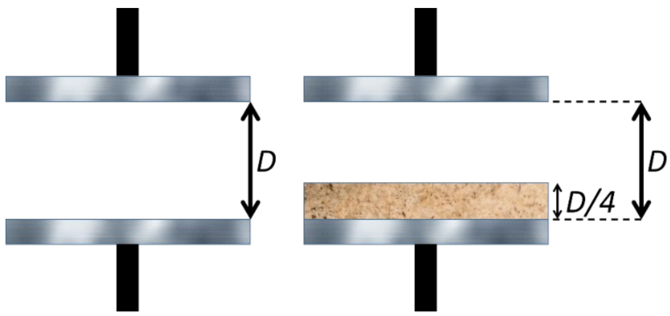


Figure 1 *Figure 2*

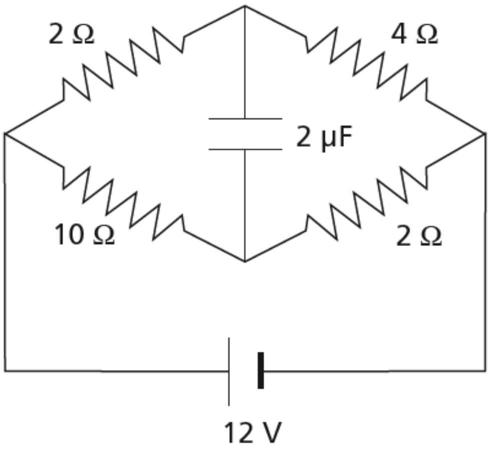
(A) $\dfrac{4K}{1+3K}$

(B) $\dfrac{4+12K}{3K}$

(C) $\dfrac{9+3K}{4K}$

(D) $\dfrac{4+3K}{7}$

Problems 25 and 26 refer to the following figure.



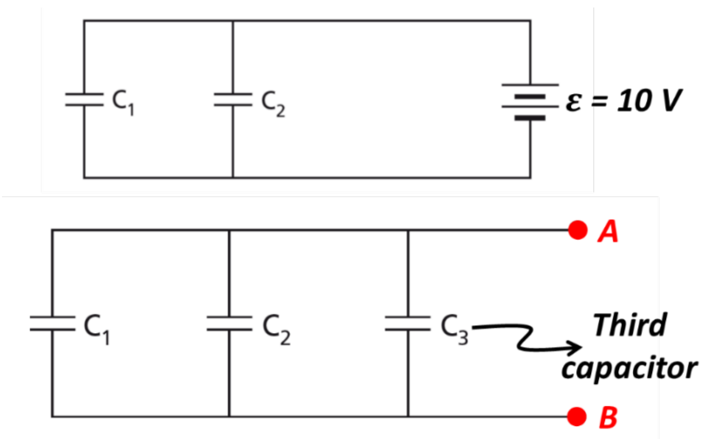
25. In the circuit shown, the capacitor has already been fully charged. What is the charge in the 2-μF capacitor?

(A) 6 μC
(B) 12 μC
(C) 15 μC
(D) 18 μC

26. What is the resistance that should replace the 10-Ω resistor to prevent the capacitor from being charged?

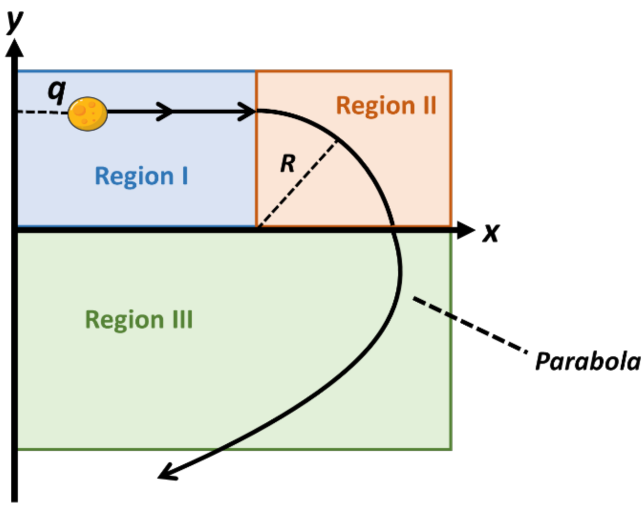
(A) 1 Ω
(B) 2 Ω
(C) 4 Ω
(D) 8 Ω

27. Two capacitors C_1 and C_2, each of 2-μF capacitance, are connected in parallel to a 10-V battery. After the capacitors are charged, the battery is removed and a third 1-μF capacitor is added to the system, as shown. This capacitor is initially uncharged. What is the potential difference V_{AB} of the new association?



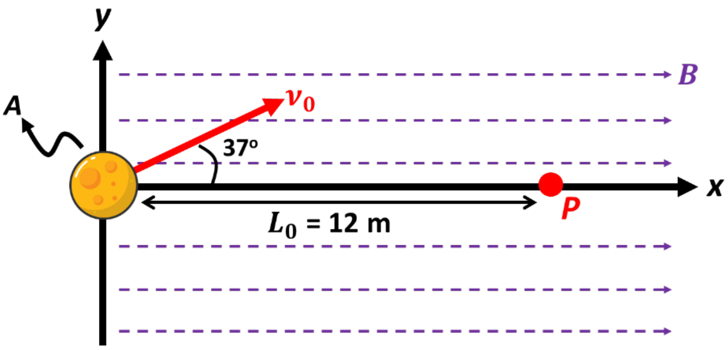
(A) 4 V
(B) 5 V
(C) 6 V
(D) 8 V

28. In each of regions I, II and III of the following figure there is a constant magnetic field $\pm E_x$ in the x-direction, or a constant electric field $\pm E_y$ in the y-direction, or a constant magnetic field $\pm B_z$ in the z-direction (perpendicular to the plane of the paper). When a positive charge q is released from point P of region I, it is accelerated uniformly, following a linear trajectory, until it enters region II. As it penetrates region II, the charge begins to outline a circular trajectory of radius R with uniform speed. Finally, as it penetrates region III, the charge describes a parabolic trajectory until it leaves the region. The following table indicates some of the possible configurations of the fields acting in the three regions. Which combination of fields is compatible with the trajectories outlined by the charge?



	(A)	(B)	(C)	(D)
Region I	E_x	E_x	E_x	B_z
Region II	E_y	B_z	B_z	E_y
Region III	B_z	$-E_x$	E_y	$-E_x$

Problems 29, 30 and 31 refer to the following figure.



29[2]**.** A proton of mass m_p = 1.6×10^{-27} kg and electrical charge q = 1.6×10^{-19} C is launched from point A with velocity v_0 = 5×10^{6} m/s in a region immersed in an uniform magnetic field B in the x-direction. Velocity v_0 makes an angle of 37° with the x-axis, as shown. The proton describes a helical trajectory, crossing the x-axis a second time at P, with the same initial speed, a distance L_0 = 12 m away from point A. What is the time required for the proton to reach point P?

(A) 3×10^{-6} s
(B) 4×10^{-6} s
(C) 3×10^{-5} s
(D) 4×10^{-5} s

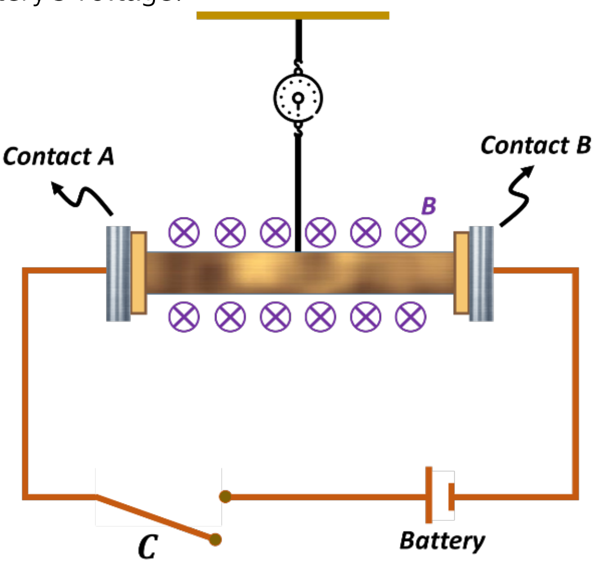
30. What is the radius of the cylinder that contains the helical trajectory outlined by the proton?

(A) 0.9 m
(B) 1.4 m
(C) 1.9 m
(D) 2.4 m

31. What is the intensity of the magnetic field B?

(A) 1.2×10^{-2} T
(B) 2.1×10^{-2} T
(C) 3.5×10^{-2} T
(D) 4.9×10^{-2} T

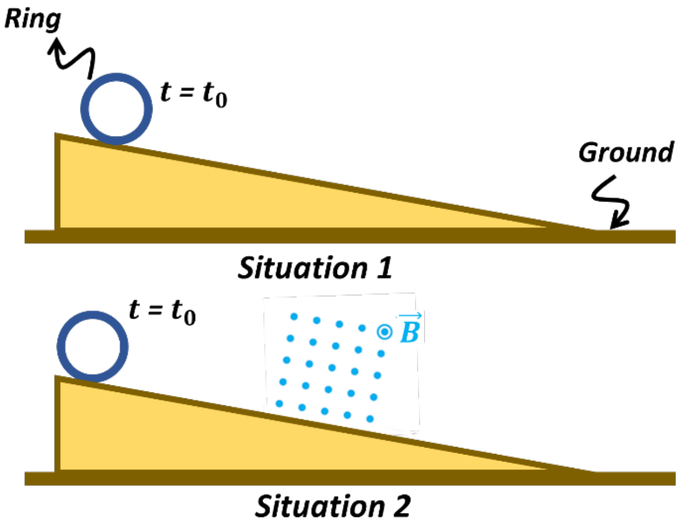
32. A rigid conducting bar of 200-g mass and 20-cm length is linked to the other parts of a circuit through two nonsliding contacts A and B, as shown. The plane of the figure is vertical. Initially, switch C is open. The conducting bar is connected to a dynamometer and subjected to a uniform 1.0-T magnetic field. Knowing that the dynamometer reads zero when switch C is closed, and that the total resistance of the circuit is 6 Ω, what is the battery's voltage?



(A) 20 V
(B) 40 V
(C) 60 V
(D) 80 V

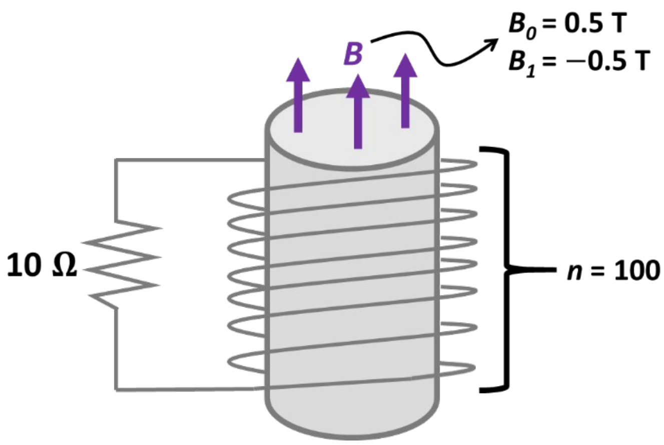
[2] *Problems 29, 30 and 31 involve analysis of the trajectory that results when a charge moves at an oblique angle relatively to a magnetic field. The AP Physics 2 syllabus proposes a quantitative treatment of trajectories in which velocity is either perpendicular or parallel to the magnetic field vector; oblique-angle configurations are covered in semi-quantitative fashion only.*

33. In situation 1, a copper ring is released from the top of a ramp at instant $t = t_0$ and rolls down until it reaches the ground at $t = t_1$. In situation 2, the ring is abandoned from the top of the same ramp at $t = t_0$; in this case, however, a segment of the ramp is immersed in an uniform magnetic field B directed out of the plane of the page, as shown. The time required for the ring to reach the ground in situation 2 is t_2. Which of the following is true?



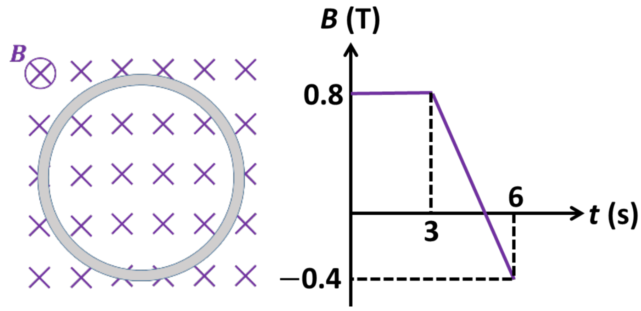
(A) t_2 is greater than t_1.
(B) t_2 equals t_1.
(C) t_2 is less than t_1.
(D) Nothing can be concluded without the intensity of magnetic field B.

34. A coil made of 100 loops of twisted wire surrounds an iron cylinder of 1-cm^2 cross-section. The coil is connected to a 10-Ω resistor, as shown. What is the amount of charge that flows in the circuit if the magnetic field that crosses the iron cylinder perpendicularly changes from 0.5 T in one direction to 0.5 T in the opposite direction?

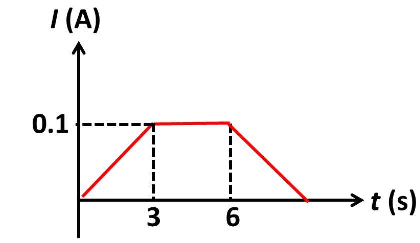


(A) 0.1 mC
(B) 1 mC
(C) 10 mC
(D) 100 mC

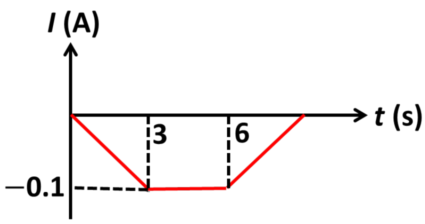
35. The magnetic field across a circular metallic loop of 2-Ω resistance and 0.5-m^2 area varies in accordance with the following graph. Which of the following graphs correctly represents the variation of the induced current in the ring?



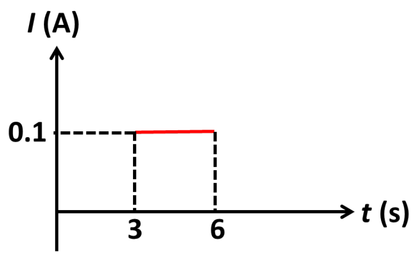
(A)



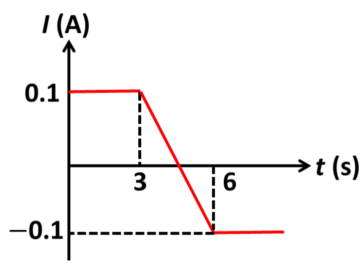
(B)



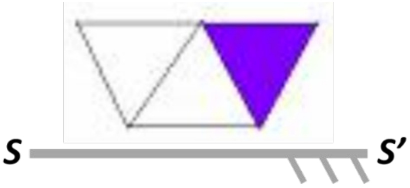
(C)



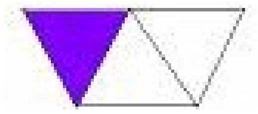
(D)



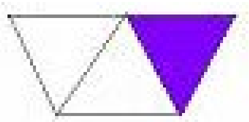
36. Which of the following alternatives correctly illustrates the image of the object shown by plane mirror SS'?



(A)

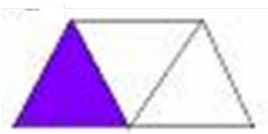


(B)

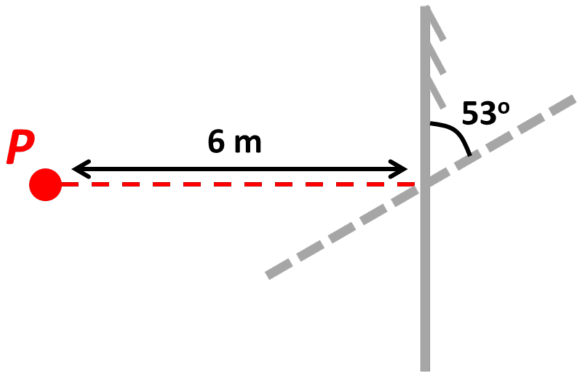


(C)

(D)

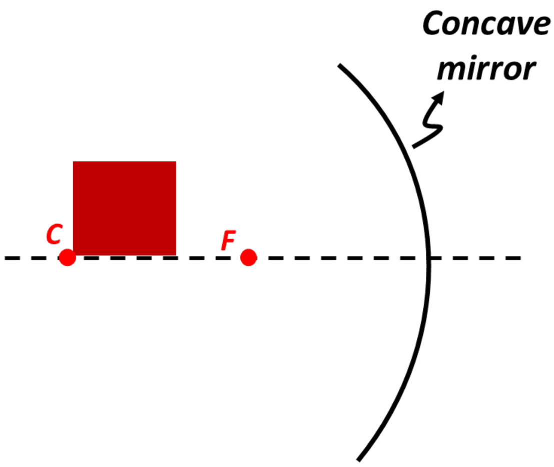


37. The figure shows a point object P located 6.0 m away from a plane mirror. If the mirror rotates by an angle of 53° relatively to its original position, as shown in the figure, what will be the distance between P and its new image?



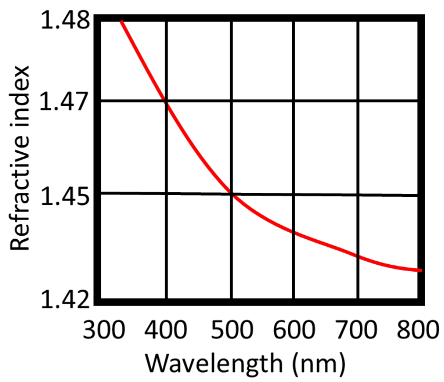
(A) 6.2 m
(B) 6.7 m
(C) 7.2 m
(D) 7.7 m

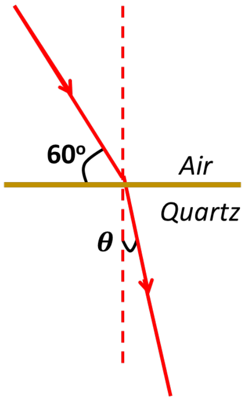
38. A square is placed over the axis of a concave spherical mirror, as shown. The lower left vertex of the square coincides with the mirror's center of curvature. Accordingly, the image of the square should be shaped like a:



(A) Triangle.
(B) Rectangle.
(C) Trapezoid.
(D) Rhombus.

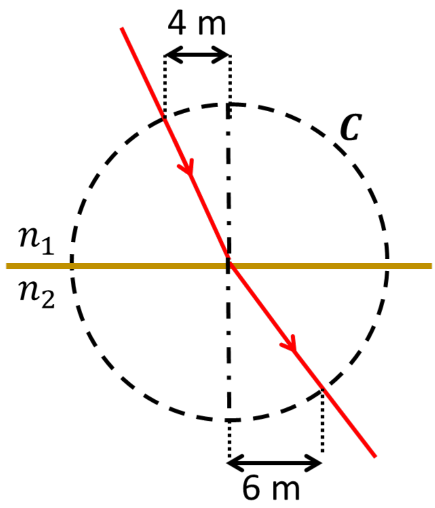
39. The refractive index of a quartz-based glass depends on the wavelength of incident light in accordance with the following graph. For light of 400-nm wavelength striking a quartz sample as shown in the illustration to the right, what is the refraction angle θ?





(A) 15°
(B) 20°
(C) 25°
(D) 28°

40. A focused light beam strikes the plane boundary between two media. The refractive indexes are n_1 and n_2 as shown. Knowing that C is a circumference, the value of ratio n_2/n_1 is:



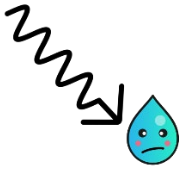
(A) 2/3
(B) 3/4
(C) 3/2
(D) 4/3

41. The minimum frequency that a given radiation must have to extract electrons from a tungsten plate is 1.1×10^{15} Hz. What is the photoelectric work function for tungsten in electron-volts?

(A) 4.6 eV
(B) 6.4 eV
(C) 7.6 eV
(D) 8.4 eV

42. What is the maximum velocity with which electrons are ejected when a tungsten sample in vacuum is exposed to electromagnetic radiation with wavelength equal to 0.18 μm?
(A) 3×10^5 m/s
(B) 5×10^5 m/s
(C) 7×10^5 m/s
(D) 9×10^5 m/s

43. A 0.20-mL droplet of water is exposed to electromagnetic radiation of wavelength equal to 7500 Å. The droplet absorbs radiation at a rate of 10^{18} photons per second. What is the time required for the droplet to have its temperature raised by 1 K (1°C)? Water has density and specific heat capacity equal to 1000 kg/m³ and 4200 J/kg·K, respectively.



(A) 1.6 s
(B) 3.2 s
(C) 4.8 s
(D) 6.4 s

44. Uranium-235 can undergo fission when struck by a neutron with sufficient kinetic energy, yielding krypton and barium nuclei in accordance with the reaction

$$n + {}^{235}_{92}\mathrm{U} \rightarrow {}^{141}_{56}\mathrm{Ba} + {}^{x}_{y}\mathrm{Kr} + 3n$$

What are the mass number x and the atomic number y of the resulting krypton nucleus?

	x	y
(A)	92	33
(B)	92	36
(C)	94	36
(D)	90	36

45. A nuclear plant powered by uranium-235 supplies about 1350 MW of electric power to a region. To supply this amount of power, about 4000 MW of heat is produced by fission of uranium in the nuclear reactor. This heat production rate is maintained over the course of a full day of continuous operation and requires the consumption of a mass Δm of fissile U-235. Knowing that only a fraction of 0.0008 (8×10^{-4}) of the uranium supply becomes fissile material, what is the mass of uranium required to drive the plant for a full day?
(A) 2.4 kg
(B) 3.6 kg
(C) 4.8 kg
(D) 6.0 kg

Solutions

1.C. For the blocks to be in equilibrium, the buoyancy must equal the weight. Considering block 1, we write

$$B = F_g \rightarrow \rho_w V_i g = \rho_1 V_b g$$

$$\therefore \rho_w V_i = \rho_1 V_b \text{ (I)}$$

Here, ρ_w = 1000 kg/m^3 is the density of water, ρ_1 is the density of block 1, V_i is the immersed volume of the block, and V_b is the total volume of the block. From the geometry of block 1, we have

$$\rho_w V_i = \rho_1 V_b \rightarrow \rho_w \times (\ell \times 2\ell \times 2\ell) = \rho_1 \times (2\ell \times 2\ell \times 2\ell)$$

$$\therefore 4\rho_w \ell^3 = 8\rho_1 \ell^3$$

$$\therefore \rho_1 = \frac{\rho_w}{2} = 500 \text{ kg/m}^3$$

Equality (I) also applies to block 2,

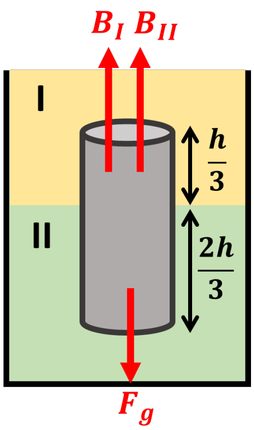
$$\rho_w V_i = \rho_2 V_b \rightarrow \rho_w \times (2\ell \times 4\ell \times 4\ell) = \rho_2 \times (4\ell \times 4\ell \times 4\ell)$$

$$\therefore 32\rho_w \ell^3 = 64\rho_2 \ell^3$$

$$\therefore \rho_2 = \frac{\rho_w}{2} = 500 \text{ kg/m}^3$$

The two blocks have the same density.

2.C. A free-body diagram of the cylinder is shown below.



Let S denote the cross-sectional area of the cylinder. Summing forces in the vertical direction gives

$$\Sigma F_y = 0 \rightarrow B_I + B_{II} = F_g$$

$$\therefore \rho_1 g (S \times h/3) + \rho_2 g (S \times 2h/3) = \rho g (S \times h)$$

$$\therefore \frac{\rho_1}{3} + \frac{2\rho_2}{3} = \rho$$

$$\therefore \boxed{\rho = \frac{\rho_1 + 2\rho_2}{3}}$$

3.D. The left and right sections have a total length $d_A + d_B = 30 + 30 = 60$ m. With a flow speed of 2 m/s, it takes 60/2 = 30 s to travel through those sections, and in the remaining 140 − 30 = 110 s water will be flowing through the hill section. This implies that the speed in the middle section is V_{hill} = 40/110 = 0.364 m/s. The radius r_{hill} of the pipe in the hill section can be found with the continuity equation,

$$V_A A_A = V_{\text{hill}} A_{\text{hill}} \rightarrow V_A \cancel{\pi} r_A^2 = V_{\text{hill}} \cancel{\pi} r_{\text{hill}}^2$$

$$\therefore r_{\text{hill}} = \sqrt{\frac{V_A}{V_{\text{hill}}}} r_A$$

$$\therefore r_{\text{hill}} = \sqrt{\frac{2}{0.364}} \times 3 = \boxed{7.03 \text{ cm}}$$

4.C. Let subscripts 1 and 2 denote conditions at the surface of the tank and at the hole, respectively. Applying Bernoulli's equation in a simplified form, we can establish the velocity V_2 with which water leaves the hole,

$$P_1 + \frac{\rho V_1^2}{2} + \rho g y_1 = P_2 + \frac{\rho V_2^2}{2} + \rho g y_2 \rightarrow V_2 = \sqrt{2 g y_1}$$

$$\therefore V_2 = \sqrt{2 \times 9.8 \times 20} = 20 \text{ m/s}$$

The flow rate is 5×10^{-3} m^3/min × 1/60 = 8.33×10^{-5} m^3/sec. The diameter d of the hole is then

$$Q = AV \rightarrow A = \frac{Q}{V}$$

$$\therefore A = \frac{8.33\times10^{-5}}{20} = 4.17\times10^{-5} \text{ m}^2$$

$$\therefore \frac{\pi d^2}{4} = 4.17\times10^{-5}$$

$$\therefore d = \sqrt{\frac{4\times\left(4.17\times10^{-5}\right)}{\pi}} = \boxed{7.29 \text{ mm}}$$

5.B. From the first law of thermodynamics,

$$Q = \Delta U + W \text{ (I)}$$

The change in internal energy for a monoatomic gas equals

$$\Delta U = \frac{3}{2} nR\Delta T \text{ (II)}$$

while the work done in an isobaric process is given by

$$W = P\Delta V$$

For an ideal gas,

$$PV = nRT$$

or, equivalently,

$$P\Delta V = nR\Delta T$$

so that, since $W = P\Delta V$,

$$P\Delta V = nR\Delta T \rightarrow W = nR\Delta T \text{ (III)}$$

Substituting (II) and (III) into equation (I) gives

$$Q = \Delta U + W \rightarrow Q = \frac{3}{2}nR\Delta T + nR\Delta T$$

$$\therefore Q = \frac{5}{2}nR\Delta T$$

The fraction f of heat that becomes internal energy is calculated to be

$$f = \frac{\Delta U}{Q} = \frac{\frac{3}{2}nR\Delta T}{\frac{5}{2}nR\Delta T} = \frac{3}{5} = \boxed{60\%}$$

6.A. Solving the first law for ΔU, we write

$$Q = \Delta U + W \rightarrow \Delta U = Q - W$$

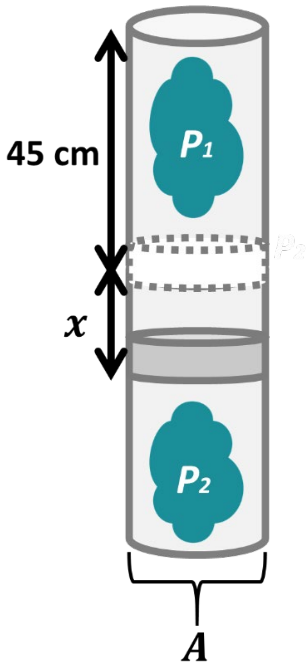
The heat transferred to the system is Q = 400 J. The work W is found by noting that the energy involved in the expansion of the gas corresponds to the elastic potential energy $kx^2/2$ in the spring; mathematically,

$$W = E_{\text{elastic}} = \frac{kx^2}{2} = \frac{1500 \times 0.4^2}{2} = 120 \text{ J}$$

so that

$$\Delta U = Q - W = 400 - 120 = \boxed{280 \text{ J}}$$

7.C. The system, when placed in the vertical, adjusts itself in such a manner that the piston is lowered by x.



For an isothermal process, product PV is conserved; that is,

$$P_1V_1 = P_2V_2 \rightarrow P_1(45+x)A = P_2(45-x)A$$

$$\therefore \cancel{P_1}\times(45+x)\times\cancel{A} = 2\cancel{P_1}\times(45-x)\times\cancel{A}$$

$$\therefore 45+x = 2(45-x)$$

$$\therefore 45+x = 90-2x$$

$$\therefore 3x = 45$$

$$\therefore \boxed{x = 15 \text{ cm}}$$

8.C. We were given the heat and work involved in process PQM, Q_{PQM} = 20 kJ and W_{PQM} = 8 kJ. We can use these two quantities to establish the change in internal energy associated with process PQM,

$$Q_{PQM} = \Delta U_{PQM} + W_{PQM} \rightarrow \Delta U_{PQM} = Q_{PQM} - W_{PQM}$$

$$\therefore \Delta U_{PQM} = 20-8 = 12 \text{ kJ}$$

Our goal is to determine the heat involved in process PRM,

$$Q_{PRM} = \Delta U_{PRM} + W_{PRM}$$

Here, W_{PRM} = 3 kJ as given. Internal energy is an extensive property and depends only on the initial and final state of the system. Since processes PRM and PQM both begin and end in the same conditions, we can surmise that ΔU is the same for the two processes, giving

$$\Delta U_{PRM} = \Delta U_{PQM} = 12 \text{ kJ}$$

Finally,

$$Q_{PRM} = \Delta U_{PRM} + W_{PRM} = 12+3 = \boxed{15 \text{ kJ}}$$

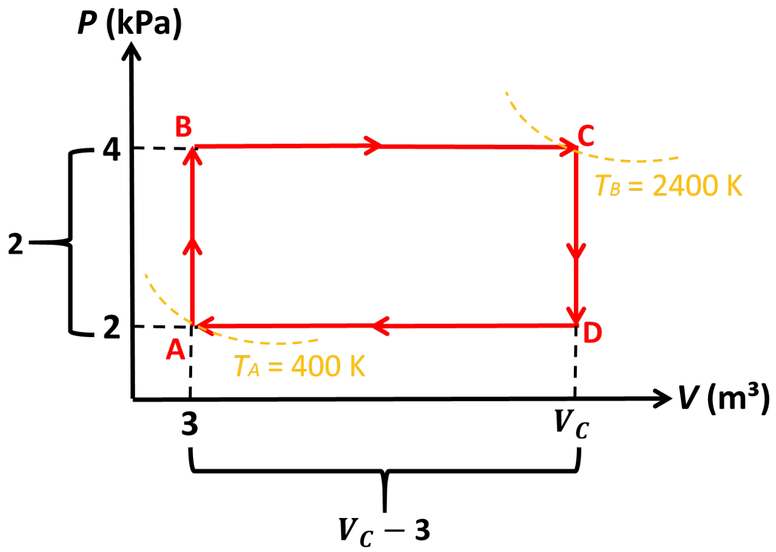
9.C. As can be seen, $D \rightarrow A$ and $B \rightarrow C$ are isobaric processes. Process $A \rightarrow B$ can be described by a linear equation $P' = C'T'$, where C' is a constant. Appealing to the ideal gas law, we may write

$$P'V' = nRT' \rightarrow P' = \left(\frac{nR}{V'}\right)T'$$

so that, comparing with $P' = C'T'$, we see that

$$C' = \frac{nR}{V'}$$

If C' and product nR are constants, volume V' has to be constant, too. Accordingly, process AB is an isochoric process. The same can be shown for process CD. Equipped with this information, we can transfer thermodynamic cycle $A \rightarrow B \rightarrow C \rightarrow D$ to a pressure-volume plane, as shown.



Now, determining the work done in cycle $ABCD$ becomes merely a matter of establishing the area of rectangle $ABCD$, namely

$$W_{ABCD} = A_{ABCD} = (4-2)\times(V_C-3)$$
$$\therefore W_{ABCD} = 2(V_C-3)$$

Volume V_C is determined as

$$\frac{P_A V_A}{T_A} = \frac{P_C V_C}{T_C} \rightarrow \frac{2\times 3}{400} = \frac{4\times V_C}{2400}$$
$$\therefore V_C = 9\ \text{m}^3$$

Finally,

$$W_{ABCD} = 2\times(9-3) = \boxed{12\ \text{kJ}}$$

10.A. The rms speed is given by

$$\bar{v} = \sqrt{\frac{3k_B T}{m}}$$

where k_B is Boltzmann's constant, T is temperature, and m is mass. Applying this relation to states (1) and (3), we have

$$\bar{v}_1 = \sqrt{\frac{3k_B T_1}{m}}\ ;\ \bar{v}_3 = \sqrt{\frac{3k_B T_3}{m}}$$

The ratio we are looking for is then

$$\frac{\bar{v}_3}{\bar{v}_1} = \frac{\sqrt{\frac{3k_B T_3}{m}}}{\sqrt{\frac{3k_B T_1}{m}}} = \sqrt{\frac{T_3}{T_1}}\ \text{(I)}$$

Process 1 → 3 is represented by a horizontal line in the pressure-volume plane and hence must be isobaric. Thus, we may write

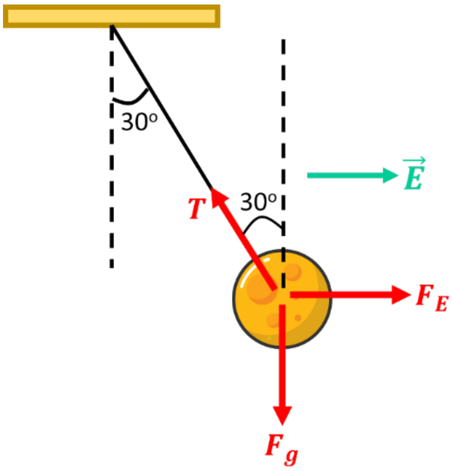
$$\frac{V_1}{T_1} = \frac{V_3}{T_3} \rightarrow \frac{0.5}{T_1} = \frac{2}{T_3}$$

$$\therefore \frac{T_3}{T_1} = \frac{2}{0.5} = 4$$

Substituting in (I) yields

$$\frac{\overline{v}_3}{\overline{v}_1} = \sqrt{\frac{T_3}{T_1}} = \sqrt{4} = \boxed{2}$$

11.D. A free-body diagram of the charge is shown below.



Tension T in the string can be found by adding forces in the vertical,

$$\Sigma F_y = 0 \rightarrow T\cos 30^\circ - F_g = 0$$

$$\therefore T = \frac{F_g}{\cos 30^\circ} = \frac{0.84}{0.866} = 0.97\,\text{N}$$

Applying Newton's second law in the horizontal, we can determine electrical force F_E,

$$\Sigma F_x = 0 \rightarrow F_E - T\sin 30^\circ = 0$$

$$\therefore F_E = T\sin 30^\circ = 0.97 \times 0.5 = 0.485\ \text{N}$$

It remains to determine the intensity of electric field E,

$$F_E = |q|E \rightarrow E = \frac{F_E}{|q|}$$

$$\therefore E = \frac{0.485}{50 \times 10^{-6}} = \boxed{9.7 \times 10^3\ \text{N/C}}$$

12.D. As the block reaches point B, it will be under the effect of weight F_g, a downward electric force F_E, and the normal reaction N, which is the force we want to evaluate. These three forces are added to produce the centripetal resultant F_{cp}; in mathematical terms,

$$N-\left(F_g+F_E\right)=F_{cp}=\frac{mv_B^2}{R}$$

$$\therefore N-\left[5\times 9.8+\left(30\times 10^{-6}\right)\times\left(5\times 10^5\right)\right]=\frac{5\times 3^2}{2.5}$$

$$\therefore N-\left(49+15\right)=18$$

$$\therefore N=18+64=\boxed{82\text{ N}}$$

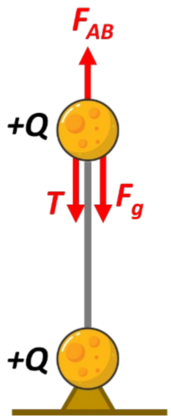
13.C. Statement (A) is correct: the surface of a conductor in electrostatic equilibrium is equipotential in nature. Statement (B) is correct: the intensity of the electric field inside a conductor in electrostatic equilibrium amounts to zero. Statement (D) is correct: the intensity of the electrical potential inside the surface of a conductor equals that on the surface and is different from zero. Lastly, statement (C) is false: the intensity of the electric field is greater at the tips and vertices of a surface than elsewhere; in the case at hand, $E_D > E_A$, not the contrary.

14.B. Before the string is cut, equilibrium of forces in the vertical brings to

$$F_{AB}-F_g-T=0\rightarrow F_{AB}=F_g+T$$

$$\therefore F_{AB}=0.2\times 9.8+8=9.96\approx 10\,\text{N}$$

$$\therefore KQ^2=10$$



Since F_{AB} = 9.96 > F_g = 2 N, sphere A will rise after the string is cut. Because F_{AB} is a variable force, an energy method is the best approach. Recall that the work done by nonconservative forces accounts for the variation in mechanical and electrical energy,

$$\Sigma W_{NCF}=\Delta E_m+\Delta U$$

In the case at hand, there are no nonconservative forces doing work, so the sum $\Delta E_m + \Delta U$ must be conserved. Right before the wire is cut, we have

$$\left(E_m+U\right)_1=m_A g h_0+\frac{KQ^2}{h_0}$$

When sphere A reaches its maximum height, we have

$$\left(E_m + U\right)_2 = m_A g\left(y + h_0\right) + \frac{KQ^2}{\left(y + h_0\right)}$$

Equating the two previous results and noting that KQ^2 = 10, it follows that

$$m_A g\left(y + h_0\right) + \frac{KQ^2}{\left(y + h_0\right)} = m_A g h_0 + \frac{KQ^2}{h_0}$$

$$\therefore 0.2 \times 9.8\left(y+1\right) + \frac{10}{\left(y+1\right)^2} = 0.2 \times 9.8 \times 1 + \frac{10}{1^2}$$

$$\therefore \frac{2\left(y+1\right)^2}{\left(y+1\right)} + \frac{10}{\left(y+1\right)} = 2 + 10$$

$$\therefore 2\left(y+1\right)^2 + 10 = 12\left(y+1\right)$$

Dividing through by 2,

$$2\left(y+1\right)^2 + 10 = 12\left(y+1\right) \to \left(y+1\right)^2 + 5 = 6y + 6$$

Expanding $(y + 1)^2$,

$$\left(y+1\right)^2 + 5 = 6y + 6 \to y^2 + 2y + 1 + 5 = 6y + 6$$

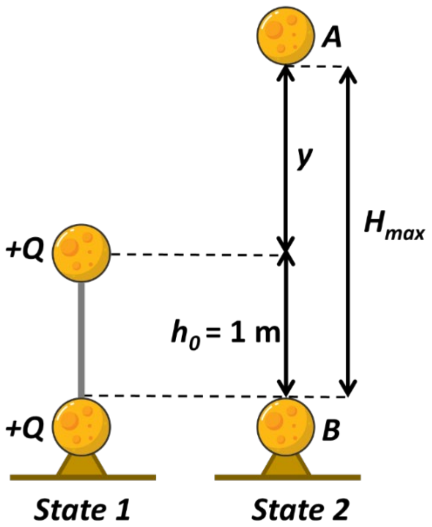
$$\therefore y^2 + 2y + \cancel{6} = 6y + \cancel{6}$$

$$\therefore y^2 = 4y$$

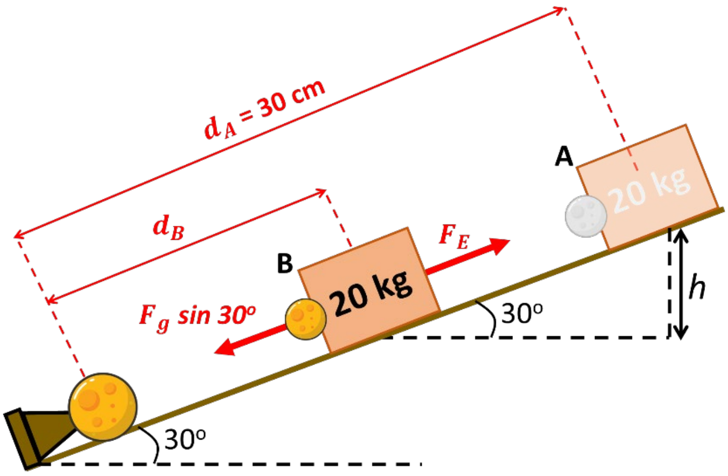
$$\therefore y = 2\,\text{m}$$

Finally,

$$H_{\max} = y + h_0 = 2 + 1 = \boxed{3\,\text{m}}$$



15.C. We were asked to determine the maximum kinetic energy, $(KE)_{max}$. Kinetic energy will be maximum when the resultant on the block equals zero. In the following schematic, this happens at point B of the block's sliding trajectory.



The work done by the electrical force should account for the variation in mechanical energy between points A, at the start of the sliding trajectory, and B, in which the block has reached maximum speed. We shall use point B as a datum for zero gravitational potential energy. In mathematical terms,

$$W_{F_E} = (E_m)_B - (E_m)_A \rightarrow W_{F_E} = \left[(KE)_B + (E_{\text{pot}})_B\right] - \left[(KE)_A + (E_{\text{pot}})_A\right]$$

$$\therefore q(V_A - V_B) = \left[(KE)_B + \cancel{(E_{\text{pot}})_B}\right] - \left[\cancel{(KE)_A} + (E_{\text{pot}})_A\right]$$

$$\therefore q(V_A - V_B) = (KE)_{\max} - (E_{\text{pot}})_A$$

$$\therefore q\left(\frac{KQ}{d_A} - \frac{KQ}{d_B}\right) = (KE)_{\max} - mgh$$

$$\therefore KQq\left(\frac{1}{d_A} - \frac{1}{d_B}\right) = (KE)_{\max} - mgh$$

$$\therefore (KE)_{\max} = KQq\left(\frac{1}{d_A} - \frac{1}{d_B}\right) + mgh \text{ (I)}$$

In order to determine $(KE)_{max}$, we require d_B and h. Appealing to Coulomb's law in point B, we get

$$F_{AB} = \frac{K|q||Q|}{d_B^2} = F_g \sin 30^\circ \rightarrow d_B = \sqrt{\frac{K|q||Q|}{F_g \sin 30^\circ}}$$

$$\therefore d_B = \sqrt{\frac{(9\times10^9)\times(9\times10^{-6})\times(10\times10^{-6})}{(20\times9.8)\times\sin 30^\circ}} = 0.0909 \text{ m} \approx 9 \text{cm}$$

Height h follows from elementary trigonometry,

$$\sin 30^\circ = \frac{h}{d_A - d_B} \rightarrow 0.5 = \frac{h}{0.3 - 0.09}$$

$$\therefore h = 0.105 \text{ m}$$

Finally, substituting all data in (I) brings to

$$(KE)_{\max} = \left(9\times10^{9}\right)\times\left(10\times10^{-6}\right)\times\left(9\times10^{-6}\right)\times\left(\frac{1}{0.3}-\frac{1}{0.09}\right)+20\times9.8\times0.105 = \boxed{14.3\text{ J}}$$

16.B. Recall that negative charges under the effect of an electric field are displaced from lower to greater potential. In order to travel from a region of greater potential to one of lower potential, as in the trajectory from P to N, an external agent must do work on the system. The work of this external force, added to the work done by the electrical force, must account for the variation in kinetic energy; in mathematical terms,

$$W_{P\to N}^{\text{ext}} + W_{P\to N}^{F_E} = \Delta KE$$

We were given $W_{P\to N}^{\text{ext}} = 0.36$ J. Further, $W_{P\to N}^{F_E} = q(V_P - V_N)$. Substituting above gives

$$W_{P\to N}^{\text{ext}} + W_{P\to N}^{F_E} = \Delta KE \to 0.36 + q\left(V_P - V_N\right) = \frac{mv_N^2}{2} - \frac{mv_P^2}{2}$$

Since the particle begins at rest, $v_P = 0$. Further, potentials $V_P = 120$ V and $V_N = 40$ V can be gleaned from the figure. It follows that

$$0.36 + q\left(V_P - V_N\right) = \frac{mv_N^2}{2} - \frac{mv_P^2}{2} \to 0.36 + \left(-2\times10^{-3}\right)\times\left(120-40\right) = \frac{\left(4\times10^{-3}\right)\times v_N^2}{2} - 0$$

$$\therefore 0.36 - 0.16 = 0.002v_N^2$$

$$\therefore v_N = \sqrt{\frac{0.36-0.16}{0.002}} = \boxed{10\text{ m/s}}$$

17.B. As the particle presses forward along the x-direction, it is driven by an electric force F_E. The variation in mechanical (in this case, kinetic only) energy equals the work done by F_E in the trajectory from $x_1 = 2$ m to $x_2 = 4$ m; that is,

$$W_{x_1\to x_2}^{F_E} = \Delta E_m \to W_{x_1\to x_2}^{F_E} = \frac{mv_2^2}{2} - \frac{m\cancel{v_1^2}}{2}$$

$$\therefore W_{x_1\to x_2}^{F_E} = \frac{mv_2^2}{2} \text{ (I)}$$

Since the electric field E_x varies in intensity, however, force F_E will likewise change in intensity. The intensities of E_x at $x = 2$ m and $x = 4$ m can be determined from the geometry of the graph. First, E_1 is such that

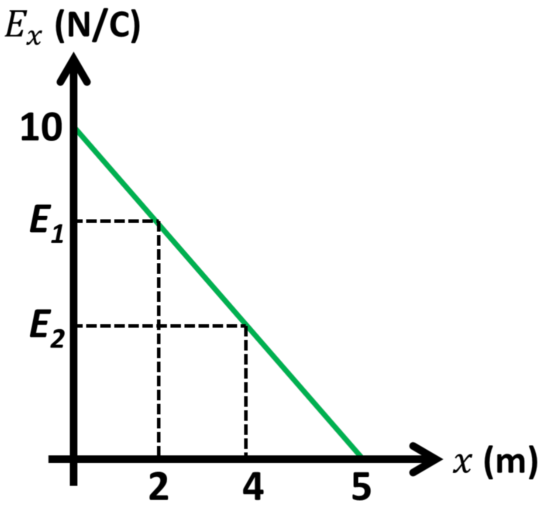
$$\frac{2}{5} = \frac{10-E_1}{10} \to 20 = 50 - 5E_1$$

$$\therefore E_1 = 6\text{ V}$$

Next, E_2 is given by

$$\frac{4}{5} = \frac{10-E_2}{10} \to 40 = 50 - 5E_2$$

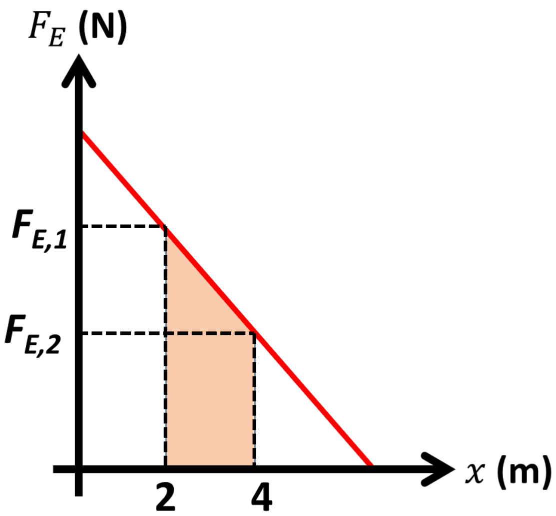
$$\therefore E_2 = 2\text{ V}$$



Noting that F_E equals the product of field intensity and electric charge, we can convert the vertical axis above into a force axis by multiplying electric field intensities E_1 and E_2 by q = 8×10^{-3} C.

$$F_{E,1} = qE_1 = \left(8\times10^{-3}\right)\times6 = 48\times10^{-3}\text{ N}$$

$$F_{E,2} = qE_2 = \left(8\times10^{-3}\right)\times2 = 16\times10^{-3}\text{ N}$$



The area under a graph of force versus distance yields work; in the case at hand,

$$W_{x_1\to x_2}^{F_E} = \frac{\left(F_{E,1}+F_{E,2}\right)\times\left(4-2\right)}{2} = \frac{\left(48\times10^{-3}+16\times10^{-3}\right)\times2}{2} = 0.064\text{ J}$$

Returning to (I) with this result, it follows that

$$W_{x_1\to x_2}^{F_E} = \frac{mv_2^2}{2} = 0.064$$

$$\therefore v_2 = \sqrt{\frac{0.064\times2}{\left(2\times10^{-3}\right)}} = \boxed{8\text{ m/s}}$$

18.C. The trajectory of the electron is described by the kinematic equation

$$\Delta y = y_0 + v_0 t + \frac{at^2}{2} \rightarrow \Delta y = 0 + 0 \times t + \frac{at^2}{2}$$

$$\therefore \Delta y = \frac{at^2}{2}$$

where we have posited that y_0 = 0 (taking the position of the lower plate as the initial position) and v_0 = 0 (the particle begins at rest). Solving for acceleration gives

$$\Delta y = \frac{at^2}{2} \rightarrow a = \frac{2\Delta y}{t^2}$$

From Newton's second law, we have $F_R = ma$, giving

$$F_R = ma = \frac{2m\Delta y}{t^2}$$

The resultant is the electrical force $F_E = |q|E$, so that

$$\frac{2m\Delta y}{t^2} = |q|E \rightarrow E = \frac{2m\Delta y}{|q|t^2}$$

$$\therefore E = \frac{2\times\left(9\times10^{-31}\right)\times0.1}{\left(1.6\times10^{-19}\right)\times\left(50\times10^{-9}\right)^2} = \boxed{450\text{ V/m}}$$

19.C. After the electron is launched, it begins to describe a ballistic trajectory that should be familiar to Physics 1 students. In this case, the downward forces are the electric force, F_E, and the weight of the electron, F_g. The electric force has a magnitude of

$$F_E = |q|E = \left(1.6\times10^{-19}\right)\times100 = 1.6\times10^{-17}\text{ N}$$

while the weight is determined as

$$F_g = mg = \left(9\times10^{-31}\right)\times9.8 = 8.82\times10^{-30}\text{ N}$$

Since the electric force is over 10 orders of magnitude greater than the gravitational force, it makes sense to model the motion of the electron as impelled by F_E only. The downward acceleration of the electron is constant and given by

$$F_E = ma \rightarrow a = \frac{F_E}{m}$$

$$\therefore a = \frac{1.6\times10^{-17}}{9\times10^{-31}} = 1.78\times10^{13}\text{ m/s}^2$$

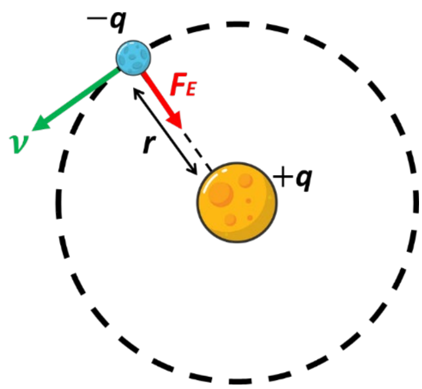
Initially, the vertical component of the electron's velocity is $v_{0,y}$ = $v_0 \sin 30^{\circ}$ = 2×10^5 m/s. By the time the electron crosses the x-axis again, it will have attained a vertical speed equal in magnitude but of opposite direction; that is, $v_{y,\text{final}}$ = −2×10^5 m/s. This should occur within a time t such that

$$v_{y,\text{final}} = v_{y,0} - at \to -2\times10^5 = 2\times10^5 - 1.78\times10^{13}t$$

$$\therefore -4\times10^5 = -1.78\times10^{13}t$$

$$\therefore t = \frac{-4\times10^5}{-1.78\times10^{13}} = 2.25\times10^{-8}\text{ s} = \boxed{22.5\text{ ns}}$$

20.B. Either of the two states of the system at hand can be described by the following schematic.



The energy to be added to the system equals $\Delta E = E_1 - E_0$, .where E_0 is the energy of the system when the orbit has a radius of 0.5 Å and E_1 is the energy of the system when the orbit has a radius of 1 Å. The energy in either state is given by the sum of an electric potential energy component, U, and a kinetic energy component, KE; mathematically,

$$E = U + KE = \frac{K(-q)(q)}{r} + \frac{m_e v^2}{2} = -\frac{Kq^2}{r} + \frac{m_e v^2}{2} \text{ (I)}$$

Noting that the electrostatic attractive force serves as the centripetal resultant, we have

$$\frac{m_e v^2}{r} = \frac{Kq^2}{r^2} \to m_e v^2 = \frac{Kq^2}{r}$$

Substituting $m_e v^2$ in (I) brings to

$$E_0 = -\frac{Kq^2}{r} + \frac{m_e v^2}{2} = -\frac{Kq^2}{r} + \frac{1}{2}\left(\frac{Kq^2}{r}\right)$$

$$\therefore E_0 = -\frac{Kq^2}{r} + \frac{Kq^2}{2r}$$

$$\therefore E_0 = -\frac{Kq^2}{2r_0}$$

where r_0 = 0.5 Å. Likewise for the final state of the orbit,

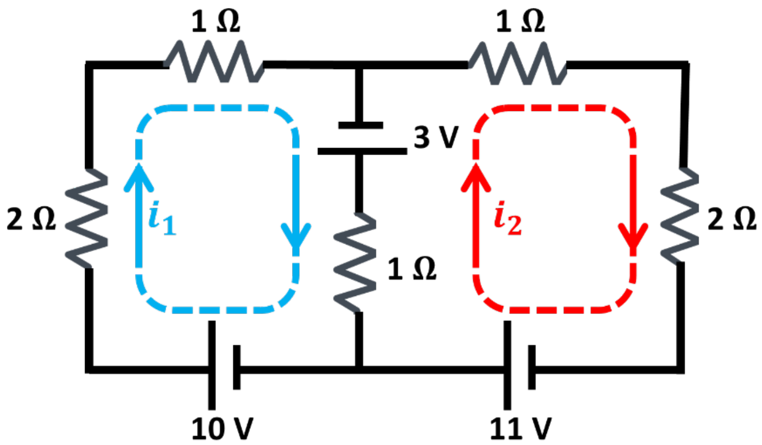
$$E_1 = -\frac{Kq^2}{2r_1}$$

where r_1 = 1 Å. The energy ΔE that must be added to the system follows as

$$\Delta E = E_1 - E_0 = -\frac{Kq^2}{2r_1} - \left(-\frac{Kq^2}{2r_0}\right) = \frac{Kq^2}{2}\left(\frac{1}{r_0} - \frac{1}{r_1}\right)$$

$$\therefore \Delta E = \frac{\left(9\times10^9\right)\times\left(1.6\times10^{-19}\right)^2}{2}\times\left(\frac{1}{0.5\times10^{-10}} - \frac{1}{1\times10^{-10}}\right) = \boxed{11.52\times10^{-19}\text{ J}}$$

21.D. We shall apply Kirchhoff's law to two closed loops, as shown.



Examining the blue loop yields

$$10 - 2i_1 - i_1 + 3 - \left(i_1 - i_2\right) = 0$$
$$\therefore 10 - 2i_1 - i_1 + 3 - i_1 + i_2 = 0$$
$$\therefore 13 - 4i_1 + i_2 = 0$$
$$\therefore i_2 = 4i_1 - 13 \text{ (I)}$$

Next, analyzing the red loop gives

$$11 - \left(i_2 - i_1\right) - 3 - i_2 - 2i_2 = 0$$
$$\therefore 11 - i_2 + i_1 - 3 - i_2 - 2i_2 = 0$$
$$\therefore 4i_2 - i_1 = 8 \text{ (II)}$$

Substituting i_2 in (II) brings to

$$4i_2 - i_1 = 8 \rightarrow 4\left(4i_1 - 13\right) - i_1 = 8$$
$$\therefore 16i_1 - 52 - i_1 = 8$$
$$\therefore 15i_1 = 60$$
$$\therefore i_1 = 4\text{ A}$$

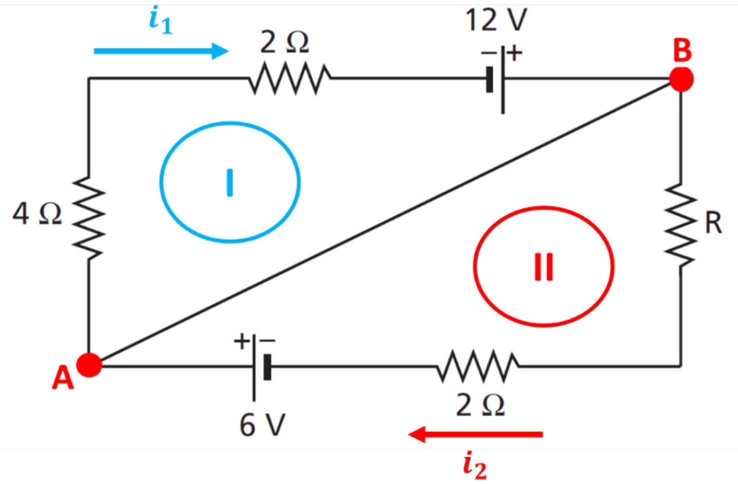
Returning to (I) with this current value, we get

$$i_2 = 4i_1 - 13 = 4\times4 - 13 = 3\text{ A}$$

Equipped with currents i_1 and i_2, determining the potential difference between points A and B becomes an easy task.

$$v_A - i_1\times1 - i_2\times1 - i_2\times2 = v_B$$
$$\therefore v_A - 4\times1 - 3\times1 - 3\times2 = v_B$$
$$\therefore v_A - 4 - 3 - 6 = v_B$$
$$\therefore v_A - v_B = \boxed{13\text{ V}}$$

22.B. We separate the system into two loops, as shown.



Applying Kirchhoff's law to loop I gives

$$12 - 4i_1 - 2i_1 = 0 \rightarrow 12 - 6i_1 = 0$$

$$\therefore i_1 = \frac{12}{6} = 2\text{ A}$$

Next, applying Kirchhoff's law to loop II yields

$$6 - Ri_2 - 2i_2 \rightarrow 6 - 10i_2 - 2i_2 = 0$$

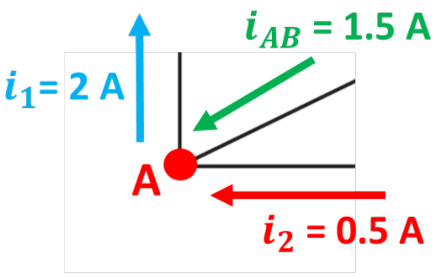
$$\therefore 6 - 12i_2 = 0$$

$$\therefore i_2 = \frac{6}{12} = 0.5\text{ A}$$

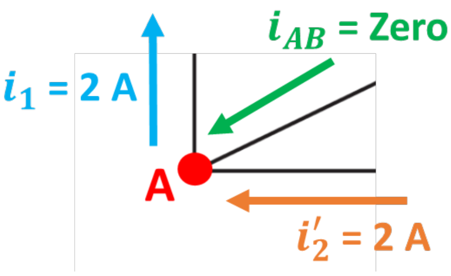
Current continuity dictates that $i_2 + i_{AB} = i_1$, or

$$i_2 + i_{AB} = i_1 \rightarrow i_{AB} = i_1 - i_2$$

$$\therefore i_{AB} = 2 - 0.5 = \boxed{1.5\text{ A}}$$



23.A. Since i_1 = 2 A, there will be no current across AB if i_2 = 2 A as well.



Applying Ohm's law brings to

$$U = R_{\text{eq}} i_2 \rightarrow 6 = (R + 2) \times 2.0$$

$$\therefore 3 = (R+2)$$

$$\therefore \boxed{R = 1\ \Omega}$$

24.A. The system in Figure 2 can be interpreted as an assemblage of two capacitors in series: the first device is a parallel-plate capacitor with $3D/4$ as the distance separating the two plates and vacuum as the medium separating the two plates; the second device is a parallel-plate capacitor with $D/4$ as the distance separating the two plates and a medium of dielectric constant K separating the plates. The capacitance of the first device, which we label C_A, is

$$C_A = \frac{\varepsilon_0 A}{\frac{3D}{4}} = \frac{4\varepsilon_0 A}{3D}$$

The capacitance of the second device, which we label C_B, is

$$C_B = \frac{K\varepsilon_0 A}{\frac{D}{4}} = \frac{4K\varepsilon_0 A}{D}$$

Capacitance C_1 is the result of an association of capacitances C_A and C_B in series,

$$C_1 = \frac{C_A C_B}{C_A + C_B} = \frac{\frac{4\varepsilon_0 A}{3D} \times \frac{4K\varepsilon_0 A}{D}}{\frac{4\varepsilon_0 A}{3D} + \frac{4K\varepsilon_0 A}{D}} = \frac{\frac{16K}{3}\left(\frac{\varepsilon_0 A}{D}\right)^{\cancel{2}}}{\cancel{\left(\frac{\varepsilon_0 A}{D}\right)}\left(\frac{4}{3} + 4K\right)}$$

$$\therefore C_1 = \frac{\frac{16K}{\cancel{3}}}{\left(\frac{4}{\cancel{3}} + \frac{12K}{\cancel{3}}\right)} \frac{\varepsilon_0 A}{D}$$

$$\therefore C_1 = \left(\frac{4K}{1+3K}\right)\frac{\varepsilon_0 A}{D}$$

This capacitance is to be compared with $C_0 = \varepsilon_0 A/D$, the capacitance of the device in Figure 1; that is,

$$\frac{C_1}{C_0} = \frac{\left(\frac{4K}{1+3K}\right)\cancel{\frac{\varepsilon_0 A}{D}}}{\cancel{\frac{\varepsilon_0 A}{D}}} = \boxed{\frac{4K}{1+3K}}$$

25.B. The equivalent resistance is

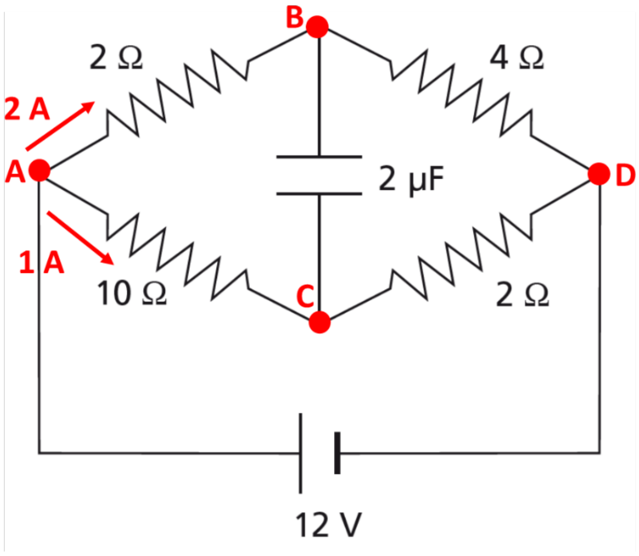
$$\frac{1}{R_{\text{eq}}} = \frac{1}{2+4} + \frac{1}{10+2} \rightarrow \frac{1}{R_{\text{eq}}} = \frac{1}{6} + \frac{1}{12}$$

$$\therefore \frac{1}{R_{\text{eq}}} = \frac{2}{12} + \frac{1}{12}$$

$$\therefore R_{\text{eq}} = 4\ \Omega$$

and the total current flowing in the circuit is $I = U/R_{\text{eq}}$ = 12/4 = 3 A. The current flowing through the ABD segment is $2i$, and the current flowing through the ACD segment is i. Since the sum of these currents must add up to 3 A, we may write

$$2i + i = 3 \rightarrow i = 1\text{A}$$



Equipped with the current values, we can establish the potential difference U_{BC} across the capacitor. First, we apply Ohm's law to segment AB,

$$U_{AB} = v_A - v_B = 2 \times 2 = 4\,\text{V}\ \text{(I)}$$

and to segment AC,

$$U_{AC} = v_A - v_C = 10 \times 1 = 10\,\text{V}\ \text{(II)}$$

Combining (I) and (II) brings to

$$-U_{AB} + U_{AC} = -(v_A - v_B) + (v_A - v_C) = -4 + 10$$

$$\therefore -\cancel{v_A} + v_B + \cancel{v_A} - v_C = 6$$

$$\therefore v_B - v_C = U_{BC} = 6\ \text{V}$$

Lastly, the charge in the capacitor is calculated to be

$$Q = CU_{AB} = \left(2 \times 10^{-6}\right) \times 6 = \boxed{12\ \mu\text{C}}$$

26.A. For the capacitor not to be charged, the potential difference between points B and C must equal zero. This can be achieved by having the circuit be organized as a Wheatstone bridge. The value of R, the resistance that replaces the 10-Ω resistor, is calculated to be

$$2 \times 2 = R \times 4 \rightarrow R_4 = \frac{4}{4} = \boxed{1\ \Omega}$$

27.D. Consider first the two-capacitor circuit. The initial system has two 2-μF capacitors connected in parallel, which can be replaced by a single device of capacitance C_{eq} = 2 + 2 = 4 μF. The charge carried by this equivalent capacitor is calculated as

$$Q = C_{\text{eq}}\varepsilon = \left(4\times10^{-6}\right)\times10 = 40\,\mu\text{C}$$

Since the two devices are identical and connected in parallel, capacitors C_1 and C_2 each carry 20 μC.

Consider now the three-capacitor system. The key to analyze this system is to bear in mind that charges must be conserved; that is, if Q_1, Q_2, and Q_3 denote the charges stored by each of the three capacitors, we must have

$$Q_1 + Q_2 + Q_3 = 40\,\mu\text{C} \;\; (\text{I})$$

Potential difference V_{AB} is the same in each of the three capacitors, so we may write, for capacitor 1,

$$Q = CU \rightarrow Q_1 = C_1 V_{AB}$$

$$\therefore Q_1 = \left(2\times10^{-6}\right)\times V_{AB}$$

Proceeding similarly with capacitors 2 and 3 yields

$$Q_2 = \left(2\times10^{-6}\right)\times V_{AB}$$

$$Q_3 = \left(1\times10^{-6}\right)\times V_{AB}$$

Substituting Q_1, Q_2 and Q_3 into (I) brings to

$$Q_1 + Q_2 + Q_3 = 40\times10^{-6} \rightarrow 2V_{AB} + 2V_{AB} + V_{AB} = 40$$

$$\therefore 5V_{AB} = 40$$

$$\therefore \boxed{V_{AB} = 8\text{ V}}$$

28.B. In region I, the charge is being accelerated in the direction of the x-axis, most likely due to an electric force provided by an electric field E_x in the direction of the particle's motion. In region II, the circular trajectory is of course driven by B_z, a magnetic field perpendicular to the velocity of the particle. Lastly, in region III the charge enters a parabolic trajectory, bending toward the negative x-axis due to the action of electric field $-E_x$.

29.A. The time Δt required for the proton to cross the x-axis a second time depends solely on the horizontal (x-)component of its initial velocity. The component of velocity in question is $v_{0,x}$ = 5×10^6 × cos 37° = 4×10^6 m/s. Accordingly, Δt is such that

$$v_{0,x} = \frac{L_0}{\Delta t} \rightarrow \Delta t = \frac{L_0}{v_{0,x}}$$

$$\therefore \Delta t = \frac{12}{4\times10^6} = \boxed{3\times10^{-6}\text{ s}}$$

30.B. As the proton advances in uniform linear motion in the x-axis, it will also describe a circle with tangential velocity $v_{0,y} = v_0 \sin 37^\circ = 3\times10^6$ m/s and a magnetic force F_m as the centripetal resultant. The composition of the linear motion along the x-axis and the circular motion driven by F_m gives rise to the helical trajectory described in the problem statement. The time Δt determined just now is not just the time required for the proton to cross the x-axis again; it is also the time required to the proton to outline a complete circumference in the circular component of its motion. If R is the radius of the circular trajectory, we may write

$$v_{0,y} = \frac{2\pi R}{\Delta t} \to R = \frac{v_{0,y}\Delta t}{2\pi}$$

$$\therefore R = \frac{\left(3.0\times10^{6}\right)\times\left(3.0\times10^{-6}\right)}{2\pi} = \boxed{1.43 \text{ m}}$$

31.B. Noting that magnetic force F_m is the centripetal resultant of the proton's movement, it follows that

$$F_m = |q| v_{0,y} B \sin\theta = \frac{m_p v_{0,y}^2}{R}$$

$$\therefore |q| \cancel{v_{0,y}} B \underbrace{\sin\theta}_{=1} = \frac{m_p v_{0,y}^{\cancel{2}}}{R}$$

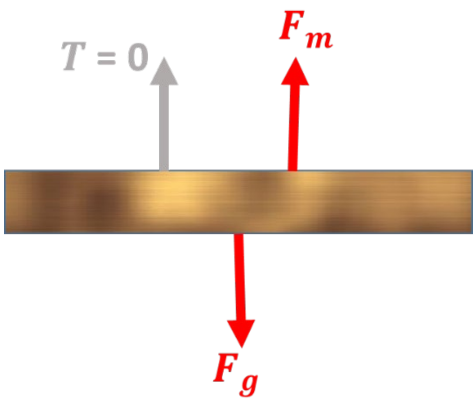
$$\therefore |q| B = \frac{m_p v_{0,y}}{R}$$

$$\therefore B = \frac{m_p v_{0,y}}{|q| R} = \frac{\left(1.6\times10^{-27}\right)\times\left(3\times10^{6}\right)}{\left(1.6\times10^{-19}\right)\times1.43} = 0.021 = \boxed{2.1\times10^{-2}\text{ T}}$$

32.C. If the dynamometer reads zero when the switch is closed, the tension in the string must be zero and the magnetic force F_m must balance the weight F_g of the conducting bar. Thus,

$$F_m = F_g \to i\ell B = mg$$

$$\therefore i = \frac{mg}{\ell B}$$

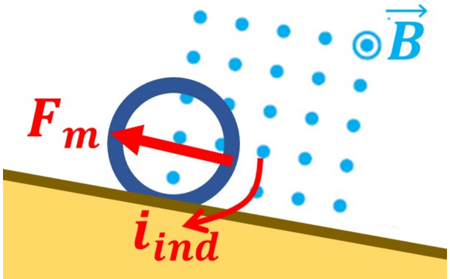


To find the tension U in the battery, we substitute i in Ohm's law, giving

$$U = Ri \rightarrow U = \frac{mgR}{\ell B}$$

$$\therefore U = \frac{0.2 \times 9.8 \times 6}{0.2 \times 1.0} = 58.8 \approx \boxed{60\text{ V}}$$

33.A. As the ring penetrates the magnetic field and as the ring leaves the magnetic field, an induced current flows through it. As a result, magnetic forces directed uphill decelerate the downward motion of the ring. It follows that the time t_2 required for the ring to reach the ground in situation 2 is greater than t_1.



Also in furtherance of the $t_2 > t_1$ conclusion is the fact that, as the ring traverses the magnetic field in situation 2, the induced current that flows in the ring causes it to heat up by Joule effect. This thermal energy comes at the expense of kinetic energy and ultimately contributes to the deceleration of the ring.

34.B. Following Faraday's law, the induced emf in the circuit is given by

$$\varepsilon_{\text{ind}} = n\frac{\Delta\Phi}{\Delta t}$$

where we have added a factor n to account for the number of loops in the coil. Substituting in Ohm's law brings to

$$I = \frac{\varepsilon_{\text{ind}}}{R} = \frac{n\Delta\Phi}{R\Delta t}$$

From the definition of current, $I = q/\Delta t$, or

$$I = \frac{q}{\Delta t} = \frac{n\Delta\Phi}{R\Delta t} \rightarrow q = \frac{n\Delta\Phi}{R}$$

Noting that $\Delta\Phi = (\Delta B)A$, we get

$$q = \frac{n\Delta\Phi}{R} \rightarrow q = \frac{nA\Delta B}{R}$$

Substituting $n = 100$, $A = 10^{-4}$ m², $R = 10\ \Omega$, and $\Delta B = 0.5 - (-0.5) = 1.0$ T, we obtain

$$q = \frac{nA\Delta B}{R} = \frac{100 \times 10^{-4} \times 1.0}{10} = 10^{-3}\text{ C} = \boxed{1\text{mC}}$$

35.C. The variation of magnetic field intensity can be divided into three intervals, namely $t \in [0; 3]$, $t \in [3; 6]$, and $t \in [6; \infty]$.

First, in $0 < t < 3$ s, B is constant and equal to 0.8 T. The induced emf is given by $\varepsilon_{\text{ind}} = |\Delta\Phi|/\Delta t$ but, in the interval in question, $\Delta\Phi = 0$ and hence $\varepsilon_{\text{ind}} = 0$. Since there is no induced emf, there will be no induced current.

Next, in 3 < t < 6 s, B varies linearly from 0.8 to −0.4 T, and with it comes a change in magnetic flux such that

$$|\Delta\Phi| = |\Delta B|A = |-0.4-(0.8)|\times 0.5 = 0.6 \text{ Wb}$$

To this value of |ΔΦ| there corresponds an induced emf given by

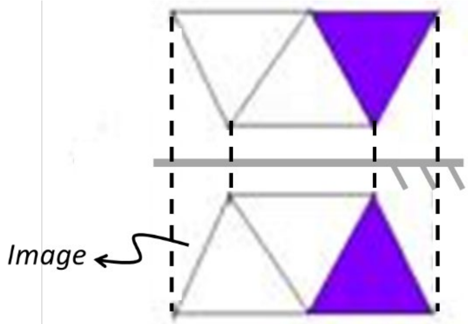
$$\varepsilon_{\text{ind}} = \frac{|\Delta\Phi|}{\Delta t} = \frac{0.6}{3} = 0.2 \text{ V}$$

As a result, an induced current i_{ind} will flow in the ring; its intensity is given by Ohm's law,

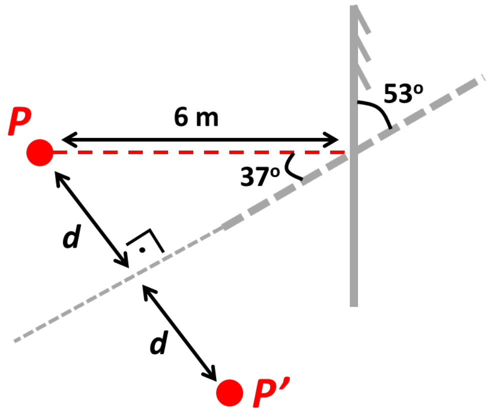
$$i_{\text{ind}} = \frac{\varepsilon_{\text{ind}}}{R} = \frac{0.2}{2} = 0.1 \text{ A}$$

Finally, in 6 < t < ∞, B is constant and equal to −0.4 T. Because there is no variation in magnetic flux, there is no induced emf and no induced current. The variation in induced current with time is correctly represented by the graph in option (C).

36.C. The mirror image of the object is illustrated below.



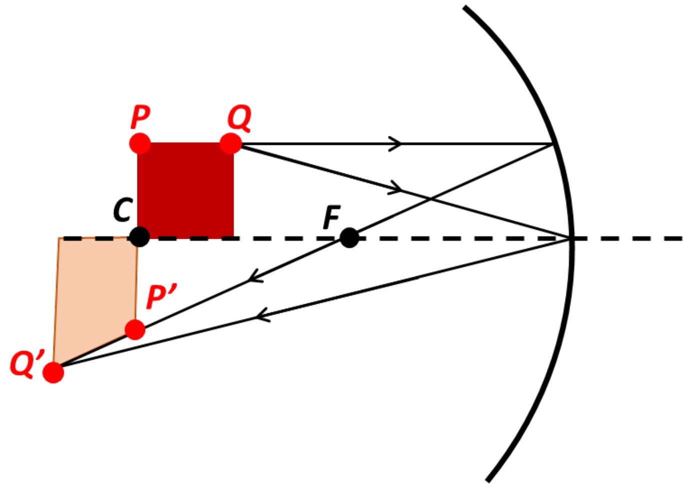
37.C. As the mirror is rotated, the distance between point P and the plane of the mirror becomes d, as shown.



Noting that d = 6 sin 37° = 3.61 m, the distance from P to the new image is calculated to be

$$\overline{PP'} = 2d = 2\times 3.61 = \boxed{7.22 \text{ m}}$$

38.C. Since one of the vertical edges of the square is in same vertical axis as the center of curvature, its image should have the same size as the real object; in the figure below, $\overline{CP} = \overline{CP'}$. Projecting two rays from Q, another of the square's vertices, reveals that the image of the square should be shaped like a trapezoid.



39.B. Inspecting the graph, we see that the refractive index for 400-nm light is n_2 = 1.47. Further, we have θ_1 = 30°, the incidence angle of the Incoming light, and n_1 = 1.0, the refractive index of air. Applying Snell's law yields

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \rightarrow \sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$$

$$\therefore \sin\theta_2 = \frac{1.0}{1.47}\times\sin 30^\circ = 0.340$$

$$\theta_2 = \sin^{-1} 0.340 = \boxed{19.9^\circ}$$

40.A. Adjusting Snell's law, we obtain

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \rightarrow \frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2} \quad \text{(I)}$$

From the geometry of the figure, we see that

$$\sin\theta_1 = \frac{4}{R}$$

and

$$\sin\theta_2 = \frac{6}{R}$$

where R is the radius of the circumference. Substituting in (I), we ultimately obtain

$$\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2} = \frac{4/R}{6/R} = \boxed{\frac{2}{3}}$$

41.A. The work function is the product of Planck's constant and the minimum frequency required to extract electrons from the material,

$$\phi = hf_{\text{min}} = \left(4.14\times10^{-15}\right)\times\left(1.1\times10^{15}\right) = \boxed{4.6 \text{ eV}}$$

42.D. We first determine the energy E of a photon of 0.18-μm wavelength,

$$E = hf = \frac{hc}{\lambda} = \frac{\left(4.14\times10^{-15}\right)\times\left(3.0\times10^{8}\right)}{\left(0.18\times10^{-6}\right)} = 6.9 \text{ eV}$$

Equipped with this result and ϕ = 4.6 eV, we can establish the maximum kinetic energy made available for a given electron,

$$E = E_{c,\max} + \phi \rightarrow 6.9 = E_{c,\max} + 4.6$$

$$\therefore E_{c,\max} = 2.3 \text{ eV}$$

$$\therefore E_{c,\max} = 2.3 \cancel{\text{eV}} \times 1.6\times10^{-19} \frac{\text{J}}{\cancel{\text{eV}}} = 3.68\times10^{-19} \text{ J}$$

The velocity that corresponds to this amount of kinetic energy is

$$E_{c,\max} = \frac{m_e v^2}{2} \rightarrow v = \sqrt{\frac{2E_{c,\max}}{m_e}}$$

$$\therefore v = \sqrt{\frac{2\times\left(3.68\times10^{-19}\right)}{9\times10^{-31}}} = \boxed{9.04\times10^{5} \text{ m/s}}$$

43.B. The energy delivered by a single photon is

$$E = hf = \frac{hc}{\lambda} = \frac{\left(6.63\times10^{-34}\right)\times\left(3.0\times10^{8}\right)}{\left(7500\times10^{-10}\right)} = 2.65\times10^{-19} \text{ J}$$

The droplet is being irradiated with 10^{18} photons in each second, so the energy input is $2.65\times10^{-19} \times 10^{18}$ = 0.265 J/s. The energy required to increase the temperature of the droplet by 1°C is

$$Q = mc\Delta T = \left(0.2\times10^{-3}\right)\times4200\times1 = 0.84 \text{ J}$$

In order to achieve the temperature change in question, the water sample must be irradiated for a time t such that

$$t = \frac{0.84 \text{ J}}{0.265 \frac{\text{J}}{\text{s}}} = \boxed{3.17 \text{ s}}$$

44.B. To establish the mass number of Kr, bear in mind that the sum of mass numbers on one side of the equation must equal the sum of mass numbers on the other. On the left-hand side, the mass numbers amount to 235 + 1 = 236. On the right-hand side, we have A = 141 from the barium nucleus and A = 3 from the three neutrons, leaving us with 236 – 141 – 3 = 92 amu for the krypton nucleus. Similar reasoning applies to the atomic number. On the left-hand side, we have Z = 92 from the uranium nucleus; neutrons are neutral and do not contribute to Z. On the right-hand side, we have Z = 56 from barium, which leaves us with 92 − 56 = +36 for the krypton nucleus.

45.C. Since the plant produces heat at a rate of 4000 MW, we surmise that 4000×10^{6} J of heat are produced per second, which amounts to

$4000\times10^6 \times 86{,}400 = 3.46\times10^{14}$ J over the course of a day. Noting that $E = \Delta mc^2$, the mass Δm of uranium associated with this heat rating is

$$E = \Delta mc^2 \rightarrow \Delta m = \frac{E}{c^2}$$

$$\therefore \Delta m = \frac{3.46\times10^{14}}{\left(3.0\times10^8\right)^2} = 3.84\times10^{-3}\ \text{kg}$$

However, only a fraction of 0.0008, or 8×10^{-4} of the uranium sample becomes fissile material. Thus, the mass M of uranium required to power the reactor becomes

$$M = \frac{\Delta m}{8\times10^{-4}} = \frac{3.84\times10^{-3}}{8\times10^{-4}} = \boxed{4.8\ \text{kg}}$$

Answer Summary

1	**C**	**16**	**B**	**31**	**B**
2	**C**	**17**	**B**	**32**	**C**
3	**D**	**18**	**C**	**33**	**A**
4	**C**	**19**	**C**	**34**	**B**
5	**B**	**20**	**B**	**35**	**C**
6	**A**	**21**	**D**	**36**	**C**
7	**C**	**22**	**B**	**37**	**C**
8	**C**	**23**	**A**	**38**	**C**
9	**C**	**24**	**A**	**39**	**B**
10	**A**	**25**	**B**	**40**	**A**
11	**D**	**26**	**A**	**41**	**A**
12	**D**	**27**	**D**	**42**	**D**
13	**C**	**28**	**B**	**43**	**B**
14	**B**	**29**	**A**	**44**	**B**
15	**C**	**30**	**B**	**45**	**C**

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