SINGAPORE JUNIOR PHYSICS OLYMPIAD 2011
GENERAL ROUND

3 August, 2011

2:30 pm – 4:00 pm

Time Allowed: ONE hour THIRTY minutes

INSTRUCTIONS

1. This paper contains **50** multiple choice questions and **21** printed pages.

2. Each of the questions or incomplete statements is followed by five suggested answers or completions. Select the one that is best in each case and then shade the corresponding bubble on the answer sheet.

3. Only the answer sheet will be collected at the end of the test. Answers written anywhere else will not be marked.

4. Use 2B pencil only. Using any other type of pencil or pen may result in answers unrecognizable by the machine.

5. Answer all questions. Marks will **NOT** be deducted for wrong answers.

6. Scientific calculators are allowed in this test.

7. A table of information is given in page 2.

TABLE OF INFORMATION

$$\text{Acceleration due to gravity at Earth surface, } g = 9.80 \text{ m/s}^2$$

$$\text{Universal gas constant, } R = 8.31 \text{ J/(mol} \cdot \text{K)}$$

$$\text{Vacuum permittivity, } \epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/(\text{N} \cdot \text{m}^2)$$

$$\text{Vacuum permeability, } \mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m/A}$$

$$\text{Atomic mass unit, } u = 1.66 \times 10^{-27} \text{ kg}$$

$$\text{Speed of light in vacuum, } c = 3.00 \times 10^8 \text{ m/s}$$

$$\text{Charge of electron, } e = 1.60 \times 10^{-19} \text{ C}$$

$$\text{Planck's constant, } h = 6.63 \times 10^{-34} \text{ J} \cdot \text{s}$$

$$\text{Mass of electron, } m_e = 9.11 \times 10^{-31} \text{ kg}$$

$$\text{Mass of proton, } m_p = 1.67 \times 10^{-27} \text{ kg}$$

$$\text{Boltzmann constant, } k = 1.38 \times 10^{-23} \text{ J/K}$$

$$\text{Avogadro's number, } N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$$

$$\text{Standard atmosphere pressure, } P_0 = 1.01 \times 10^5 \text{ Pa}$$

$$\text{Density of water, } \rho_w = 1000 \text{ kg/m}^3$$

$$\text{Lorentz Transformation: } x' = \frac{x - ut}{\sqrt{1 - u^2/c^2}}$$

$$y' = y$$

$$z' = z$$

$$t' = \frac{t - ux/c^2}{\sqrt{1 - u^2/c^2}}$$

1. A car accelerates from 4.0 m/s to 24 m/s at a rate of 3.0 m/s². How far does it travel while accelerating?

   (A) 56 m
   (B) 93 m
   (C) 158 m
   (D) 195 m
   (E) 279 m

2. A marathon runner runs at a steady speed of 15 km/hr. When the runner is 7.5 km from the finish, a bird begins flying from the runner to the finish at 30 km/hr. When the bird reaches the finish line, it turns around and flies back to the runner, and then turns around again, repeating the back-and-forth trips until the runner reaches the finish line. How many kilometers does the bird travel?

   (A) 10 km
   (B) 15 km
   (C) 20 km
   (D) 30 km
   (E) 45 km

3. A 2 kg mass and a 4 kg mass on a horizontal frictionless surface are connected by a massless string A. They are pulled horizontally across the surface by a second string B with a constant acceleration of 12 m/s². What is the magnitude of the net force on the 2 kg mass?
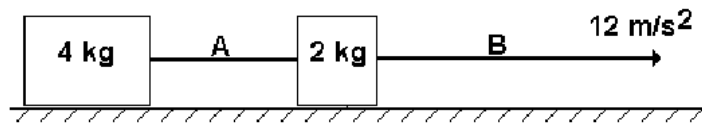

   (A) 72 N
   (B) 48 N
   (C) 24 N
   (D) 6 N
   (E) 3 N

4. Superman stands on the roof garden of a very tall building on Earth with one ball in each hand. If the red ball is thrown horizontally off the roof and the blue ball is simultaneously dropped over the edge, which statement is true? Neglect air resistance.

(A) Both balls always hit the ground at the same time with the same speed.

(B) The red ball strikes the ground first with a higher speed than the blue ball.

(C) The blue ball strikes the ground first, but with a lower speed than the red ball.

(D) Both balls always hit the ground at the same time, but the red ball has a higher speed just before it strikes the ground.

(E) If the initial speed of the red ball is high enough, it may strike the ground later with a higher speed than the blue ball.

5. A drum has a radius of 0.40 m and a moment of inertia of 4.5 $kg\,m^2$. The frictional torque of the drum axle is 3.0 N m. A 15 m length of rope is wound around the rim. The drum is initially at rest. A constant force is applied to the free end of the rope until the rope is completely unwound and slips off. At that instant, the angular velocity of the drum is 13 rad/s. The drum then decelerates and comes to a halt. The constant force applied to the rope is closest to

(A) 7.5 N

(B) 14 N

(C) 18 N

(D) 27 N

(E) 33 N

6. A tether ball is on a 2.1 m string which makes an angle of 22° with the vertical as it moves around the pole in a horizontal plane. If the mass of the ball is 1.3 kg, what is the ball's speed?

(A) 1.4 m/s

(B) 1.6 m/s

(C) 1.8 m/s

(D) 2.0 m/s

(E) 2.2 m/s

7. A block of mass m is pulled along the floor by a force T inclined at an angle θ as shown in the diagram. The magnitude of the force T is such that the block moves with uniform velocity.

   The coefficient of friction between the block and the floor is denoted by μ. The magnitude of the frictional force exerted on the block by the floor is given by

   (A) T

   (B) μmg

   (C) $T\sin\theta$

   (D) $\mu(mg - T\sin\theta)$

   (E) $\mu(mg + T\sin\theta)$
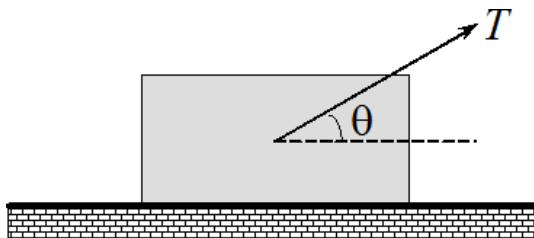
8. A 8.0 g bullet is shot into a 4.0 kg block, at rest on a frictionless horizontal surface. The bullet remains lodged in the block. The block moves toward a spring and compresses it by 9.4 cm. The force constant of the spring is 1000 N/m. The initial speed of the bullet is closest to

   (A) 710 m/s.

   (B) 740 m/s.

   (C) 770 m/s.

   (D) 800 m/s.

   (E) 830 m/s.

9. In the diagram shown below, balls A and B (of mass m_A and m_B respectively) hanging on strings of the same length are touching each other when they are at their equilibrium positions. Ball A is then slightly pulled to the left and released. Which of the following statements are correct after the first collision?

   (A) If $m_A > m_B$, the next collision will be to the right of the equilibrium position.

   (B) If $m_A < m_B$, the next collision will be to the right of the equilibrium position.

   (C) If $m_A > m_B$, the next collision will be to the left of the equilibrium position.

   (D) The next collision will be at the equilibrium position.

   (E) There is not enough information in the question to determine any of the above statements.

5
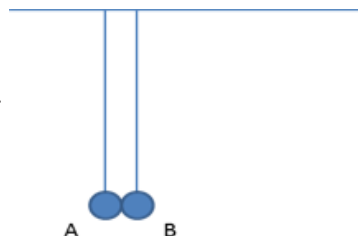
10. Two identical masses are hung on strings of the same length. One mass is released from a height H above its free-hanging position and strikes the second mass; the two stick together and move off. They rise to height h given by
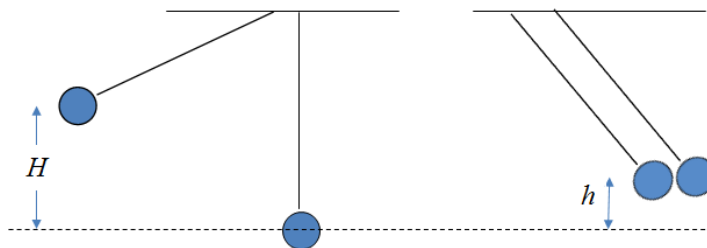

(A) $H/4$.

(B) $H/2$.

(C) $3H/4$.

(D) H.

(E) None of the above.

11. A tennis ball bounces on the floor three times. If each time it loses 23.0% of its energy due to heating, how high does it bounce after the third time, given that we released it 4.90 m from the floor?

(A) 0.0596 m

(B) 0.259 m

(C) 1.13 m

(D) 2.24 m

(E) 2.91 m

12. Two springs, S_1 and S_2, have negligible masses and the spring constant of S_1 is $1/3$ that of S_2. When a block is hung from the springs as shown below and the springs come to equilibrium again, the ratio of the work done in stretching S_1 to the work done in stretching S_2 is
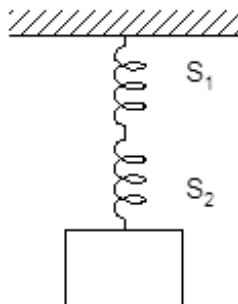
(A) 1/9

(B) 1/3

(C) 1

(D) 3

(E) 9

13. Under which of the following conditions can a ladder standing on a frictionless horizontal floor and leaning against a rough vertical wall be in equilibrium?

(A) The normal force exerted by the floor on the ladder equals the normal force the wall exerts on the ladder.

(B) The weight of the ladder is equal in magnitude to the frictional force the wall exerts on the ladder.

(C) The normal force exerted by the floor on the ladder equals the weight of the ladder.

(D) The normal force exerted by the floor on the ladder equals the frictional force the wall exerts on the ladder.

(E) A ladder in this situation cannot be in equilibrium.

14. A beaker of base 40 cm^2 contains water to a certain depth. A small block of dimensions 4 cm × 4 cm × 4 cm is being placed into the beaker. The rise in the water level is 1.2 cm. The density of the block is

(A) 0.25 that of water

(B) 0.45 that of water

(C) 0.60 that of water

(D) 0.75 that of water

(E) 1.20 that of water

15. Lithium vapour which is produced by heating lithium to the relatively low boiling point of 1340°C forms a gas of Li$_2$ molecules. Each molecule has a molecular mass of $14u$. The molecules in nitrogen gas (N$_2$) have a molecular mass of $28u$. If the Li$_2$ and N$_2$ gases are at the same temperature, which of the following is true?

(A) v_{rms} of N$_2$ = $2.00 \times v_{rms}$ of Li$_2$

(B) v_{rms} of N$_2$ = $1.41 \times v_{rms}$ of Li$_2$

(C) v_{rms} of N$_2$ = v_{rms} of Li$_2$

(D) v_{rms} of N$_2$ = $0.71 \times v_{rms}$ of Li$_2$

(E) v_{rms} of N$_2$ = $0.50 \times v_{rms}$ of Li$_2$

16. A sample of a monatomic ideal gas is taken through the cycle shown in figure below. At point a, the pressure, volume, and temperature are P_i, V_i, and T_i respectively. ($C_v = (3/2)R$ for monatomic gas)
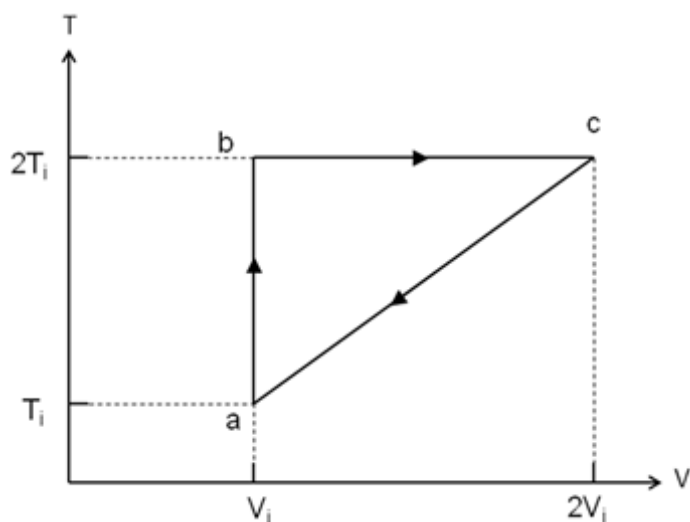

Which of the following about the processes ab, bc, ca is true?

(A) Isobaric, isothermal, adiabatic

(B) Isochoric, isobaric, isothermal

(C) Isothermal, adiabatic, isobaric

(D) Isochoric, isothermal, isobaric

(E) Isobaric, isochoric, isothermal

17. For the sample in the previous question, what is the **net** heat input into the gas during the cycle?

(A) $(2\ln 2 - 1)P_i V_i$

(B) $(\ln 2 + 1.5)P_1 V_i$

(C) $(1.5 - 2\ln 2)P_i V_i$

(D) $(1.5 - \ln 2)P_1 V_i$

(E) $(2.5 + \ln 2)P_i V_i$

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18. Heat is added at a constant rate to a sample of pure substance that is initially a solid at temperature T_0. The temperature of the sample as a function of time is shown in the graph below.

Temperature

T_2

T_1

T_0

Time
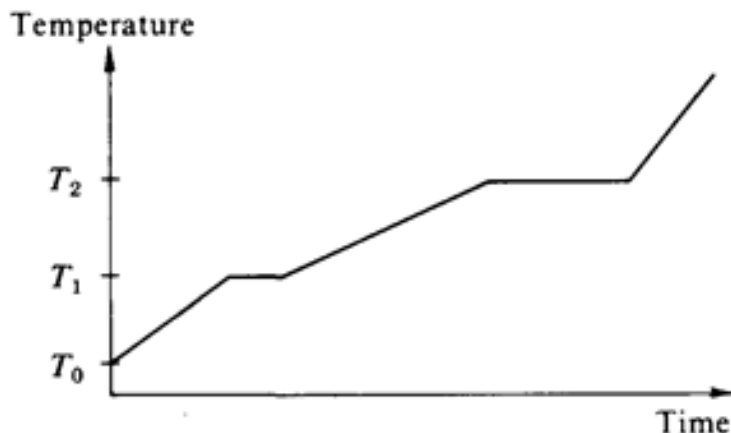
From the graph, one can conclude that the

(A) substance sublimes directly from the solid phase to the vapor phase.

(B) melting point is T_2.

(C) specific heat is greater for the liquid phase than for the solid phase.

(D) heat of fusion and heat of vaporization are equal.

(E) specific heat of the solid increases linearly with temperature.

19. Two completely identical samples of the same ideal gas are in equal volume containers with the same pressure and temperature in containers labeled A and B. The gas in container A performs non-zero work W on the surroundings during an isobaric (constant pressure) process before the pressure is reduced isochorically (constant volume) to half its initial amount. The gas in container B has its pressure reduced isochorically (constant volume) to half its initial value and then the gas performs the same amount of work W on the surroundings during an isobaric (constant pressure) process. After the processes are performed on the gases in containers A and B, which is at the higher temperature?

(A) The gas in container A

(B) The gas in container B

(C) The gases have equal temperature

(D) The value of the work W is necessary to answer this question.

(E) The value of the work W is necessary, along with both the initial pressure and volume, in order to answer the question.

20. For each breath that you take, approximately how many of the air molecules in this breath would also have been breathed by Albert Einstein during his lifetime (1879 – 1955)? The atmosphere is about 8 km thick and the density of air is about 1 kg/m³. The Earth's radius is 6.37×10^6 m. You may also assume that the air consists mainly of nitrogen with molar mass of 28 g. Make reasonable assumptions for any other data that you may need!

(A) 10^2

(B) 10^6

(C) 10^{10}

(D) 10^{14}

(E) Zero, or very little chance to breath in one such molecule.

21. The figure below shows a stretched string of length $2L$ and closed-pipes P, Q, R, S are of lengths $L/2$, L, $2L$, and $3L$ respectively. The string's tension is adjusted until the speed of waves on the string equals the speed of sound waves in the air. The fundamental mode of oscillation is then set up on the string and the string is brought near each of the pipes.

2L

P   Q   R   S
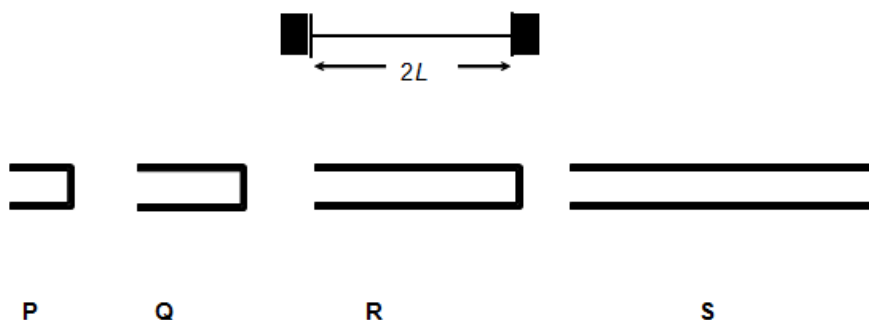
Which of the above pipe(s) is/are most likely to resonate when the string is placed near the pipes?

(A) P only

(B) Q only

(C) P and R only

(D) Q and S only

(E) Q, R and S only

22. A transverse wave is propagated in a string stretched along the x-axis. The equation of the wave, in SI units, is given by :

$$y = 0.020\cos(16t - 3.5x).$$

The amplitude of the wave is

(A) 0.020 m
(B) 16 m
(C) 3.5 m
(D) 4.6 m
(E) 0.22 m

23. For the wave in the previous question, its frequency is closest to

(A) 0.020 Hz
(B) 16 Hz
(C) 3.5 Hz
(D) 2.5 Hz
(E) 0.56 Hz

24. Two identical small conducting spheres are separated by 0.60 m. The spheres carry different amounts of charge and each sphere experiences an attractive electric force of 10.8 N. The total charge on the two spheres is -24 μC. The two spheres are connected by a slender conducting wire, which is then removed. The electric force on each sphere is closest to:

(A) Zero
(B) 3.6 N, repulsive
(C) 3.6 N, attractive
(D) 5.4 N, repulsive
(E) 5.4 N, attractive

25. The diagram below shows equipotential lines produced by an unknown charge distribution. *A, B, C, D* and *E* are points in the plane. At which point does the electric field have the greatest magnitude?
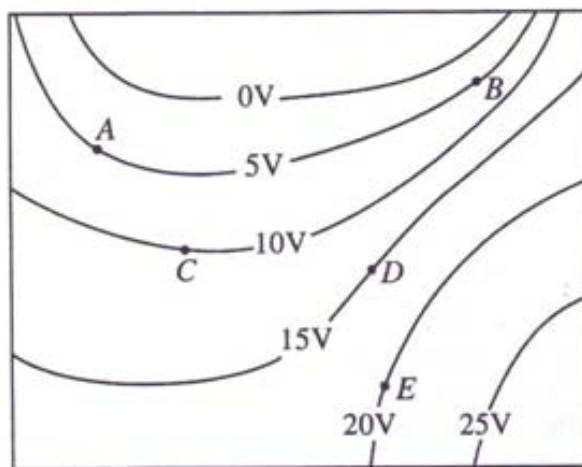
26. The surface of a thin-walled cubic insulating (nonconducting) box is given a uniformly distributed positive surface charge. Which one of the following can be inferred about the electric field everywhere inside the insulating box due to this surface charge using Gauss's law?

   (A) Its magnitude everywhere inside must be zero.

   (B) Its magnitude everywhere inside must be nonzero but uniform (the same).

   (C) Its direction everywhere inside must be radially outward from the center of the box.

   (D) Its direction everywhere inside must be perpendicular to one of the sides.

   (E) None of the above.

27. One end of a Nichrome wire of length $2L$ and cross-sectional area A is attached to an end of another Nichrome wire of length L and cross-sectional area $2A$. If the free end of the longer wire is at an electric potential of 8.0 volts, and the free end of the shorter wire is at an electric potential of 1.0 volt, the potential at the junction of the two wires is most nearly equal to

   (A) 2.4 V

   (B) 3.3 V

   (C) 4.5 V

   (D) 5.7 V

   (E) 6.6 V

28. The figure below shows the electric field lines in a region. Sadly, you do not know the charge inside the three regions marked (i), (ii), and (iii).
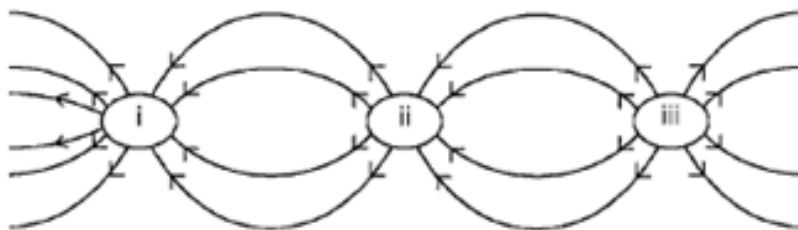
The above cross-sectional drawing is qualitatively correct. Which region (or regions) carries a net charge of the greatest magnitude?

(A) (i) only

(B) (ii) only

(C) (iii) only

(D) (ii) and (iii), which have equal net charge

(E) (i), (ii) and (iii), which have equal net charge

29. The four identical capacitors in the circuit shown below are initially uncharged.

The switch is then thrown first to position A, and then to position B. After this is done:

(A) $V_1 = V_0$

(B) $V_1 > V_2 > V_3 > V_4$

(C) $V_1 + V_2 + V_3 = V_4 = V_0$

(D) $Q_1 = Q_2 = Q_3 = Q_4$

(E) $Q_1 = 3Q_3$
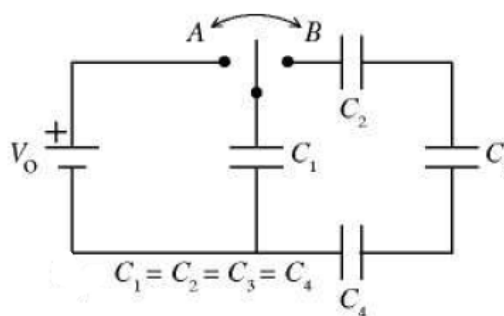
Note: $V_{1,2,3,4}$ are the potential differences across $C_{1,2,3,4}$ and $Q_{1,2,3,4}$ are the final charges stored in $C_{1,2,3,4}$ respectively.

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30. A long, thin, vertical wire has a net positive charge λ per unit length. In addition, there is a current I in the wire. A charged particle moves with speed u in a straight-line trajectory, parallel to the wire and at a distance r from the wire. Assume that the only forces on the particle are those that result from the charge on and the current in the wire and that u is much less than c, the speed of light.

Suppose that the current in the wire is reduced to $I/2$. Which of the following changes, made simultaneously with the change in the current, is necessary if the same particle is to remain in the same trajectory at the same distance r from the wire?

(A) Doubling the charge per unit length on the wire only

(B) Doubling the charge on the particle only

(C) Doubling both the charge per unit length on the wire and the charge on the particle

(D) Doubling the speed of the particle

(E) Introducing an additional magnetic field parallel to the wire

31. Following on the question above, the particle is later observed to move in a straight-line trajectory, parallel to the wire but at a distance $2r$ from the wire. If the wire carries a current I and the charge per unit length is still λ, the speed of the particle is

(A) $4u$

(B) $2u$

(C) u

(D) $u/2$

(E) $u/4$

32. A 9-volt battery is connected to four resistors to form a simple circuit as shown below. What would be the electric potential at point C with respect to point B in the circuit?

(A) +7 V

(B) +3 V

(C) 0 V

(D) -3 V

(E) -7 V

14
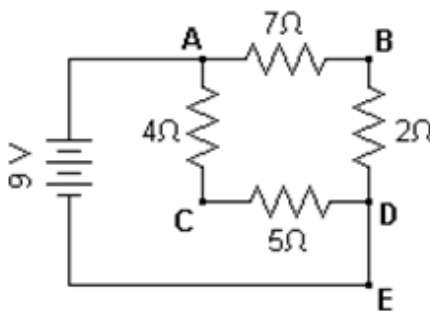
33. The current I flowing through a component varies with the potential difference V across it as shown. Which graph best represents how the resistance varies with V?
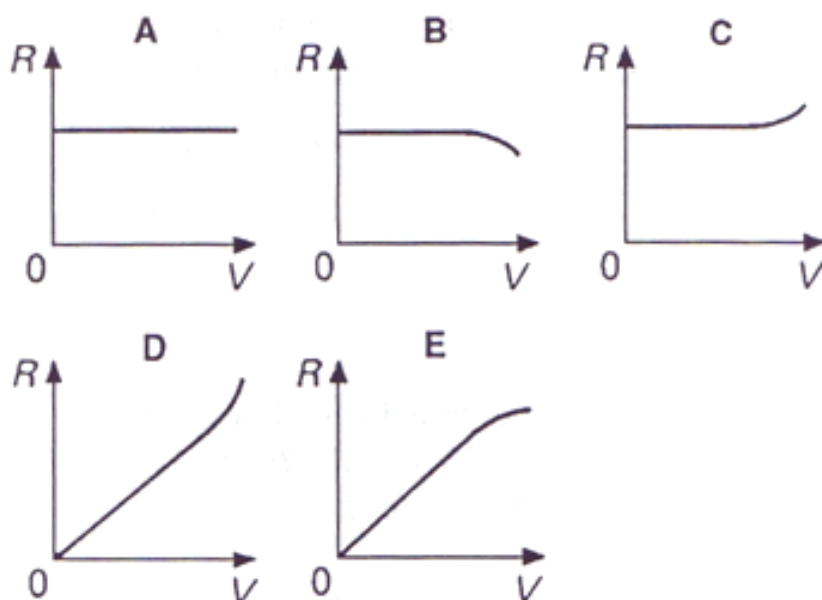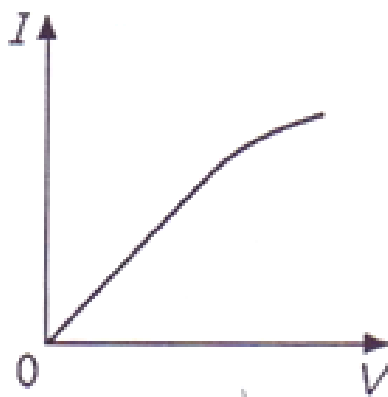
34. The circuit shown below is in a uniform magnetic field that is into the page and is decreasing in magnitude at the rate of 150 T/s. The magnitude and direction of the current in the loop is given by

(A) 0.35 A counter-clockwise

(B) 0.35 A clockwise

(C) 0.65 A counter-clockwise

(D) 0.65 A clockwise

(E) 0.85 A counter clockwise

15
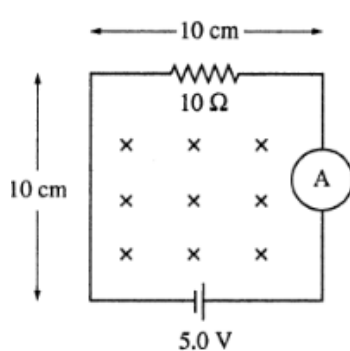
35. A materials scientist performs an experiment where he attempts to measure the resistance of a material by applying a potential difference across the material and measuring the current passing through the material. The results are displayed in the graph as shown. Which of the following are correct conclusions?

i. The resistance of the material is about $1.3\,\Omega$.

ii. The resistance of the material is about $0.75\,\Omega$.

iii. The resistance of the material is not constant as the potential difference across it changes.

iv. The material is an ohmic conductor.

v. The material is not an ohmic conductor.
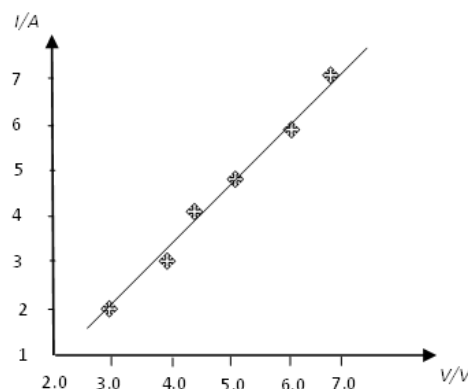
(A) i and iv

(B) ii and iv

(C) i and v

(D) iii and iv

(E) iii and v

36. An E-field and a B-field crosses each other as shown in the figure below, with the E-field pointing vertically upward. The E-field is tuned such that the force it exerts on each drop balances the drop's own weight. Oil Drops A and B both carry charges of the same magnitude and sign and are of the same mass. A is stationary and B moves in a circular path with radius R and speed v. If A and B are to collide and combine, the final charged drop will

(A) exhibit linear motion with half the speed that B used to have.

(B) exhibit uniform circular motion with radius, $R/2$.

(C) exhibit uniform circular motion with radius R.

(D) exhibit uniform circular motion with half the period that B used to have.

(E) None of the above.
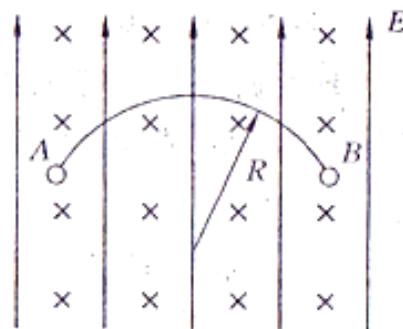
37. As you walk away from a plane mirror on a wall, your image

    (A) gets smaller.

    (B) may or may not get smaller, depending on where the observer is positioned.

    (C) is always a real image, no matter how far you are from the mirror.

    (D) changes from being a virtual image to a real image as you pass the focal point.

    (E) is always the same size.

38. A camera is used to take a photograph of the flat mirror image of an object placed at position X in the diagram shown. On which point should the camera be focused on?
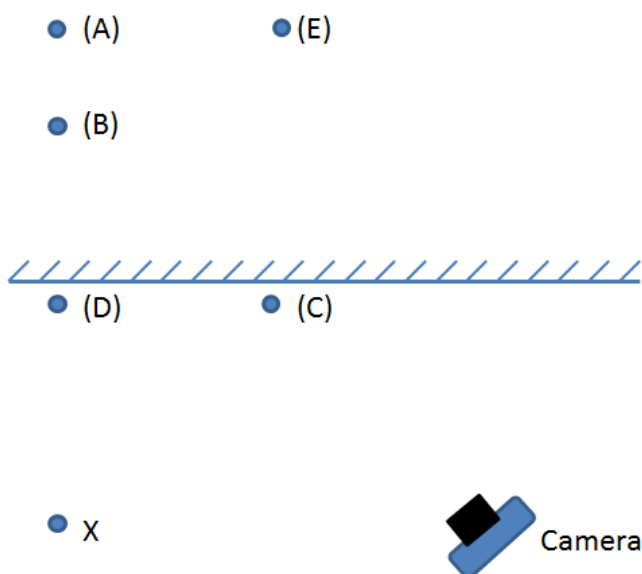
39. Unpolarized light is incident on two ideal polarizers in series. The polarizers are oriented so that no light emerges through the second polarizer. A third polarizer is now inserted between the first two and its orientation direction is continuously rotated through 180°. The maximum fraction of the incident power transmitted through all three polarizers is

    (A) zero

    (B) 1/8

    (C) 1/2

    (D) 1/4

    (E) 1

40. A 100 W light bulb is 20% efficient (i.e. 80% of its output is invisible infra-red radiation and only 20% is visible light). A person can see the light with the naked eye from a distance of 10 km on a dark night. If the area of the pupil of the persons eye is 0.50 cm^2, what power of the visible light is received by the eye of the person?

(A) 2.4×10^{-16} W

(B) 8.0×10^{-13} W

(C) 1.5×10^{-12} W

(D) 2.0×10^{-9} W

(E) 8.0×10^{-9} W

41. We are given the imaginary situation where scientists have discovered a new phenomenon called 'haon'. Various observations about haon are listed below.

   i. Haon can be reflected.

   ii. Haon can be refracted.

   iii. Haon can be diffracted.

   iv. Interference effects can be produced with haon.

   v. Haon travels through vacuum at about 3500 m/s.

"Haon can be treated as a wave phenomenon but it is not a form of electromagnetic radiation." Which observations provide the **<u>BEST</u>** evidence for the statement?

(A) i, ii and iii

(B) i and v

(C) iv and v

(D) ii and iv

(E) i, ii and iv

42. While standing outdoors one evening, you are exposed to the following four types of electromagnetic radiation: yellow light from a sodium street lamp, radio waves from an AM radio station, radio waves from an FM radio station, and microwaves from an antenna of a communications system. Rank these types of waves in terms of increasing photon energy, i.e., lowest energy first.

    (A) sodium light, AM, FM, microwave
    (B) AM, FM, sodium light, microwave
    (C) AM, FM, microwave, sodium light
    (D) microwave, sodium light, AM, FM
    (E) according to quantum physics, they are all of the same energy

43. A rocket (A) is moving with constant speed $0.8c$ relative to the earth. A second rocket (B) overtakes the first rocket with a constant speed of 40 m/s as seen by a bug riding on Rocket A. Which of the following is true about the speed of the rocket B relative to earth?

    (A) Slightly smaller than $0.8c + 40$ m/s.
    (B) Exactly $0.8c + 40$ m/s.
    (C) Slightly larger than $0.8c + 40$ m/s.
    (D) Don't know, we do not have enough information.
    (E) None of the above.

44. Rocket A is moving with constant speed 0.40c relative to the earth. Rocket B overtakes the rocket A with a constant speed of $0.87c$ (seen by the bug in rocket A). Which of the following is true about the clocks in the rockets with respect to the bug in rocket A?

    (A) Clocks in rocket A will tick at twice the rate of the clocks in rocket B.
    (B) Clocks in rocket A will tick at half the rate of the clocks in rocket B.
    (C) Clocks in rocket A will tick at a rate about one-fifth that of the clocks in rocket B.
    (D) Clocks in rocket A will tick at about the same rate as the clocks in rocket B.
   (E) None of the above.

45. Which of the following is a Lorentz transformation?

(A) $x' = 4x$, $y' = y$, $z' = z$, $t' = 0.25t$

(B) $x' = x - 0.75ct$, $y' = y$, $z' = z$, $t' = t$

(C) $x' = 1.25x - 0.75ct$, $y' = y$, $z' = z$, $t' = 1.25t - 0.75x/c$

(D) $x' = 1.25x - 0.75ct$, $y' = y$, $z' = z$, $t' = 0.75t - 1.25x/c$

(E) None of the above

46. A spaceship utilizes a large sail of highly reflective aluminium foil as an auxiliary propulsion system. If the sail area is 1.6 km^2 and is orientated for maximum efficiency in starlight of intensity 500 W/m^2 and wavelength 550×10^{-9} m, the resulting acceleration of the ship of mass 1.2×10^5 kg would be about

(A) 1.2×10^{-6} m/s^2

(B) 3.5×10^{-4} m/s^2

(C) 2.2×10^{-5} m/s^2

(D) 7.5×10^{-6} m/s^2

(E) 4.4×10^{-5} m/s^2

47. A beam of alpha particles ($q = +2e$) is directed at a uranium ($Z = 92$) target. The radius of a uranium nucleus is 7.4×10^{-15} m. The closest approach between the centres of an alpha particle to a stationary uranium nucleus is 30.0×10^{-15} m. The kinetic energy of the incident alpha particle is closest to

(A) 4.5 MeV

(B) 6.0 MeV

(C) 7.5 MeV

(D) 9.0 MeV

(E) 10.5 MeV

48. An important observation that led Bohr to formulate his model of the hydrogen atom was the fact that

(A) a low density gas emitted a series of sharp spectral lines.

(B) neutrons formed diffraction patterns when scattered from a nickel crystal.

(C) electrons were found to have a wave nature.

(D) the peak of the blackbody radiation moved to shorter wavelength as the temperature was increased.

(E) the emission of light by an atom does not appear to conserve energy.

49. X-rays of wavelength 0.098 nm scattered from a newly discovered crystalline material are observed to have a first order intensity maximum at an angle 20° measured from the incident direction as shown in the figure below.

Assuming that the material is made of elemental atoms arranged in a cubic array, what is the number density of atoms in the material?

(A) 4.45×10^{28} m^{-3}

(B) 8.90×10^{28} m^{-3}

(C) 2.27×10^{28} m^{-3}

(D) 4.30×10^{19} m^{-3}

(E) 3.40×10^{29} m^{-3}
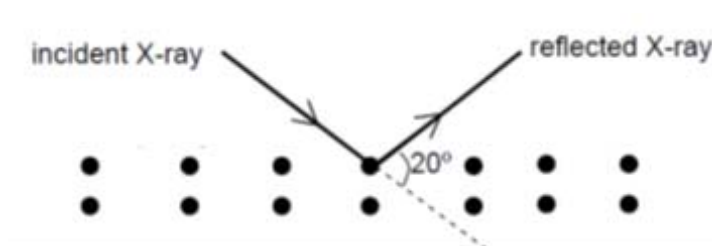
50. A radioactive nucleus with atomic number $Z = 92$ and atomic mass $A = 235$ decays through a series of alpha, beta and gamma emissions to a stable nucleus with $Z = 82$ and $A = 207$. The number of alpha particles and the number of beta particles emitted during the entire process are

(A) 8 alpha particles and 6 beta particles.

(B) 7 alpha particles and 4 beta particles.

(C) 7 alpha particles and 10 beta particles.

(D) 14 alpha particles and 7 beta particles.

(E) 18 alpha particles and 10 beta particles.

END OF PAPER.