SINGAPORE JUNIOR PHYSICS OLYMPIAD 2017
GENERAL ROUND

19 May 2017
14:30 – 16:30
Time Allowed: **TWO Hours**

INSTRUCTIONS

1. **Read the instructions on this page** but **DO NOT TURN the page** until you are told to do so by the invigilator.
2. This paper contains **50** multiple choice questions and **12** printed pages (including this cover page).
3. Each of the questions or incomplete statements is followed by five suggested answers or completions. **Select only the best** in each case and then **shade** the corresponding bubble on the OMR Answer Sheet.
4. Use **2B pencil** only to shade the bubbles on the OMR Answer Sheet, and make sure any stray markings are properly erased.
5. **Only** the **OMR Answer Sheet** will be **marked**. Answers written anywhere else will not be marked.
6. Fill in **ALL your personal particulars** listed on the OMR Answer Sheet.
7. Answer **ALL** questions. Marks will **NOT** be deducted for wrong answers so use your intuition, guess or just choose A.
8. **Scientific calculators** are **allowed** in this test. **Graphing** calculators are **not** allowed.
9. A general data sheet is given below. You may **detach the data sheet when the competition starts** so that you can refer to it easily.

GENERAL DATA SHEET

Acceleration due to gravity at Earth surface,	g	$= 9.80\ \text{m s}^{-2} = \lvert\mathbf{g}\rvert$
Universal gas constant,	R	$= 8.31\ \text{J mol}^{-1}\ \text{K}^{-1}$
Vacuum permittivity,	ε_0	$= 8.85 \times 10^{-12}\ \text{C}^2\ \text{N}^{-1}\ \text{m}^{-2}$
Vacuum permeability,	μ_0	$= 4\pi \times 10^{-7}\ \text{T m A}^{-1}$
Atomic mass unit,	u	$= 1.66 \times 10^{-27}\ \text{kg}$
Speed of light in vacuum,	c	$= 3.00 \times 10^{8}\ \text{m s}^{-1}$
Speed of sound in air,	v_s	$= 340\ \text{m s}^{-1}$
Charge of electron,	e	$= 1.60 \times 10^{-19}\ \text{C}$
Planck's constant,	h	$= 6.63 \times 10^{-34}\ \text{J s}$
Mass of electron,	m_e	$= 9.11 \times 10^{-31}\ \text{kg} = 0.000549u$
Mass of proton,	m_p	$= 1.67 \times 10^{-27}\ \text{kg} = 1.007u$
Mass of deuteron,	m_p	$= 3.34 \times 10^{-27}\ \text{kg} = 2.014u$
Rest mass of alpha particle,	m_α	$= 4.003u$
Boltzmann constant,	k	$= 1.38 \times 10^{-23}\ \text{J K}^{-1}$
Avogadro's number,	N_A	$= 6.02 \times 10^{23}\ \text{mol}^{-1}$
Standard atmosphere pressure,	P_0	$= 1.01 \times 10^{5}\ \text{Pa}$
Density of water,	ρ_w	$= 1000\ \text{kg m}^{-3}$
Specific heat (capacity) of water,	c_w	$= 4.19 \times 10^{3}\ \text{J kg}^{-1}\ \text{K}^{-1}$
Stefan-Boltzmann constant,	σ	$= 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$
Radius of the sun,	r_s	$= 696{,}000\ \text{km}$
Distance between sun and earth,	r_{SE}	$= 150{,}000{,}000\ \text{km}$
Acceleration due to gravity at the sun's surface,	g_s	$= 28.02\ \text{g}$
Temperature on the surface of the sun,	T_s	$= 5780\text{K}$

1. An electron in a vacuum, starting from rest falls 5 cm near the surface of the earth. Considering **only** the gravitational force acting on the electron, how long does it take for the electron to travel 5 cm?

A. 0.1 s
B. 0.03 s
C. 0.01 s
D. 0.001 s
E. 0.0001 s

2. In addition to the downwards gravitational field in question 1, there is an additional positive uniform electric field directed upwards in this region. Compared to question 1 and considering **only** the electric field and gravitational field, we can say that:

A. The electron will take the same time as before.
B. The electron will take a shorter time to fall 5 cm.
C. The electron will take a longer time to fall 5 cm.
D. The electron will move upwards.
E. It depends on whether the electric field or gravitational field is stronger.

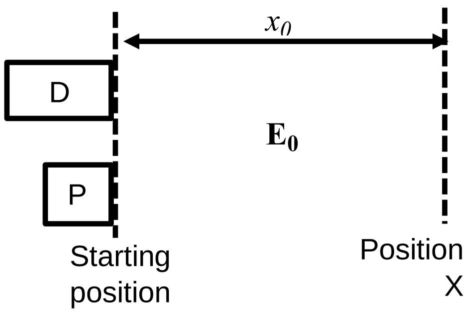
3. A uniform electric field is applied using apparatus fixed to the Earth in such a way that the electron remains motionless in the presence of both the electric and gravitational fields only. In relation to Newton's 3rd law, the reaction pair to the electrostatic force acting on the electron is:

A. The gravitational force in the opposite direction acting on the electron.
B. The electrostatic force in the opposite direction acting on the electron.
C. The electrostatic force acting on the apparatus.
D. The gravitational force acting on the earth.
E. None of the above. In this case Newton's 1st law is applicable, not the 3rd law.

4. A uniform electric field is applied in such a way that the electron moves upwards at a constant speed of 15 m s^{-1} in the presence of both the electric and gravitational fields **only**. The magnitude of the electric field is reduced to zero **suddenly** and the electron slows down to 5 m s^{-1} after moving up a further distance of:

A. 4 m
B. 6 m
C. 8 m
D. 10 m
E. 12 m

5. *Deuteron* D and *proton* P are initially moving in the same direction with the same non-relativistic initial momentum. They pass through a region of constant, strong, uniform electric field $\mathbf{E_0}$ between the starting position and position X. Consider only the effect of the electric field on each particle. Consider the momentum, p, of the particles at position X, a distance x_0 from the initial position (not necessarily at the same time). Subscripts d, p denote deuteron D or proton P. Which statement below is correct?

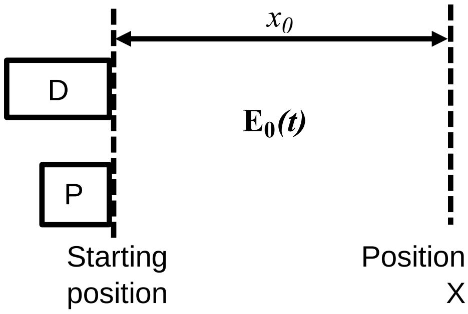


A. $p_d < p_p$
B. $p_d = p_p$
C. $p_d > p_p$
D. Some of the above depending on $\boldsymbol{E_0}$.
E. Some of the above depending on the initial momentum, $\boldsymbol{E_0}$ and x_0.

6. A *proton*, 1 with kinetic energy K_0, and another *proton*, 2, with twice the kinetic energy $2K_0$ pass through a region of constant, uniform electric field $\mathbf{E_0}$ *between the starting position and position X in the same direction as their motion*. Consider the kinetic energy, K and momentum, p of the particles at position X, a distance x_0 from the initial position (not necessarily at the same time). Subscripts 1, 2 denote proton 1 or proton 2. Which statement below is correct?

A. $2K_1 < K_2, \sqrt{2}p_1 < p_2$
B. $2K_1 < K_2, \sqrt{2}p_1 = p_2$
C. $2K_1 > K_2, \sqrt{2}p_1 > p_2$
D. $2K_1 > K_2, \sqrt{2}p_1 = p_2$
E. $2K_1 = K_2, \sqrt{2}p_1 > p_2$

7. A *deuteron*, 1 with kinetic energy K_0, and a *proton*, 2, with twice the kinetic energy $2K_0$ of the deuteron pass through a region between the starting position and position X. While the particles are passing through the region a uniform electric field $\mathbf{E_0}(t)$ in the same direction as their motion is switched on for time t_0 then switched off while the two particles are still within the region. Consider the kinetic energy, K and momentum, p of the particles when they are at position X, a distance x_0 from the initial position (not necessarily at the same time). Subscripts 1, 2 denote deuteron 1 or proton 2. Which statement below is correct?



A. $2K_1 < K_2, p_1 = p_2$
B. $2K_1 > K_2, p_1 = p_2$
C. $2K_1 > K_2, p_1 < p_2$
D. $2K_1 > K_2, p_1 > p_2$
E. $2K_1 = K_2, p_1 = p_2$

8. A *proton* moves in the presence of an electric field **only**. At a certain time the magnitude of its velocity was 100 m s^{-1}. The magnitude of velocity decreases to 72 m s^{-1} at time t, then decreases further to 60 m s^{-1} at time $2t$. It then increases again to 72 m s^{-1} at time $3t$ before reaching 100 m s^{-1} at time $4t$. Considering the time from 0 to $4t$, we can say with some certainty that:

A. The electric field strength is lower during time t to $2t$ as compared to during 0 to t.
B. The electric field vector changes direction at time $2t$.
C. The electric field vector is constant from 0 to $4t$.
D. The electric field strength decreases from 0 to $2t$ then increases again from $2t$ to $4t$.
E. The information is quite useless and we can't make any of the above statements.

9. A *proton* moves in a circle with radius 1 mm, within a region of constant uniform magnetic field, 0.1 T. What is the magnitude of the proton's linear momentum?

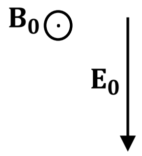
A. 0 kg m s^{-1}
B. 1.6×10^{-26} kg m s^{-1}
C. 1.6×10^{-24} kg m s^{-1}
D. 1.6×10^{-23} kg m s^{-1}
E. 5.01×10^{-19} kg m s^{-1}

10. An *electron* moves in a circle, radius 1 mm, within a region of constant uniform magnetic field, 0.1 T. What is its kinetic energy?

A. 1.6×10^{-24} J
B. 1.6×10^{-19} J
C. 1.6×10^{-16} J
D. 880 eV
E. 88 keV

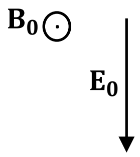
For the next few questions, we consider the case where the effect of the magnetic field is very strong. The motion of an electric charge in a magnetic field can be **visualised** as the superposition of a relatively fast circular motion ("gyrates") around a point called the guiding center and a relatively slow drift of this point. However to understand the motion, you should consider **all effects together** in **detail** and follow the particle's motion through at least four quarter cycles.

11. A *proton* gyrates in a constant, **uniform** magnetic field $\mathbf{B_0}$ outwards through paper and a constant, **uniform** electric field $\mathbf{E_0}$ is downwards. Which of the following statements is true?



A. The guiding center moves right.
B. The guiding center moves left.
C. The guiding center moves outwards.
D. The guiding center moves downwards.
E. The guiding center moves upwards.

12. An *electron* gyrates in a constant, **uniform** magnetic field $\mathbf{B_0}$ outwards through paper and a constant, **uniform** electric field $\mathbf{E_0}$ is downwards. Which of the following statements is true?

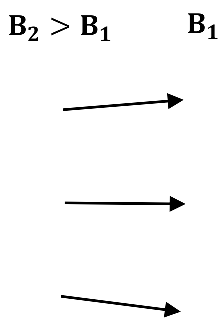


A. The guiding center moves right.
B. The guiding center moves left.
C. The guiding center moves outwards.
D. The guiding center moves downwards.
E. The guiding center moves upwards.

13. An *electron* gyrates in the presence of a constant uniform electric field with magnitude E and magnetic field, with magnitude B. The electric and magnetic fields are perpendicular to each other (see figure in Q12). The magnitude of velocity of the guiding center after time t is:

A. EB
B. E / B
C. B / E
D. eEt / m_e
E. $EB(em_e / t)^2$

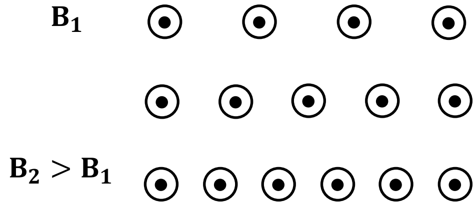
14. A *proton* gyrates and spirals in a region of non-uniform magnetic field only. Its guiding center has an initial velocity and moves naturally from the region of higher magnetic field to a region of lower magnetic field and in the direction of the magnetic field. Which of the following statements is true?



A. The velocity of the guiding center does not change because there is no work done by the magnetic force which is perpendicular to the motion.
B. The velocity of the guiding center does not change because as it moves to a region with lower magnetic field, only the radius of the gyration increase.
C. The velocity of the guiding center decreases as the velocity of the proton decreases when it moves to a region with lower magnetic field.
D. The velocity of the guiding center increases as there is a magnetic force in the direction of the magnetic field.
E. The velocity of the guiding center increases as there is a force acting on the proton with direction from high to low magnetic field.

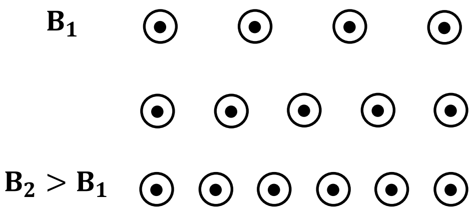
15. A *proton* is in a constant, but non-uniform magnetic field that points outwards through paper. The magnetic field gets stronger as we move downwards. Which of the following statements is true?

A. The guiding center moves outwards.
B. The guiding center moves downwards.
C. The guiding center moves upwards.
D. The guiding center moves left.
E. The guiding center moves right.



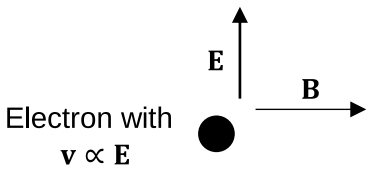
16. An *electron* is in a constant, but non-uniform magnetic field outwards through paper. The magnetic field gets stronger as we move downwards. Which of the following statements is true?

A. The guiding center moves right.
B. The guiding center moves left.
C. The guiding center moves outwards.
D. The guiding center moves downwards.
E. The guiding center moves upwards.



17. In a metal, we may consider the *electron* as being affected by the electric field but because of collisions, the electron effectively has a velocity whose **magnitude** is directly proportional to the **magnitude** of the electric field. Such an electron as shown in the figure is in a linearly polarized, uniform, plane, electromagnetic wave, with electric field oscillating up and down and magnetic field right and left (when the electric field is up, the magnetic field is right). What is the direction of force averaged over one period of the wave?

A. The force on the electron is into paper.
B. The force on the electron is out of paper.
C. The force on the electron is up.
D. The force on the electron is down.
E. Average force is zero.



18. Consider a large sphere of charge Q and radius r. What is the magnitude of the potential difference between the surface of the sphere and a point a small distance d outside (i.e. away from) the surface of the sphere? Assume $d \ll r$.

A. $Q/4\pi\varepsilon_0 r$
B. $Q/4\pi\varepsilon_0 d$
C. $Qd/4\pi\varepsilon_0 r^2$
D. $Qr/4\pi\varepsilon_0 d^2$
E. None of the above

19. Consider a large sphere of fixed protons and freely moving electrons (plasma) with radius r. The plasma is at temperature T_e and the number density of protons and electrons in the bulk of the plasma is n_e. What is the scale length d over which the outer shell of electrons can extend from the rest of the assembly proportional to? Assume $d \ll r$.

A. $\sqrt{T_e / n_e}$
B. T_e / n_e
C. $\sqrt{rT_e} / n_e$
D. $T_e / \sqrt{n_e}$
E. r

20. Consider a large sphere of fixed protons and freely moving electrons (plasma) with radius r. The plasma is at low temperature T_e and the number density of protons and electrons in the bulk of the plasma is n_e. What is the frequency at which the electrons in the thin outer shell oscillate when perturbed proportional to?

A. $n_e T_e$
B. T_e
C. T_e / n_e
D. $\sqrt{T_e / n_e}$
E. $\sqrt{n_e}$

21. An electron with kinetic energy 0.5 eV moves **vertically upwards** from the surface of the sun. Consider only gravity. Calculate the **height** the electron reaches above sun's surface.

(Hint: the potential energy of a mass m may be taken as GPE = $-mg_s \frac{r_s^2}{r}$.)

A. 0.46 r_s
B. 0.73 r_s
C. 0.85 r_s
D. 0.97 r_s
E. 1.12 r_s

22. Consider two isolated hydrogen atoms coming from opposite directions, each with initial velocity, v, of 2700 ms^{-1}. They meet, are attracted to each other and form a hydrogen molecule with a bond length, l, of 0.075 nm and bond dissociation energy, E, of 4.5 eV. The perpendicular distance d between the two atoms trajectory was initially 1.5 nm when they were still far away from each other. Based on classical mechanics, in general the molecule may move linearly, rotate and/or vibrate. Assuming the amplitude of vibration is small compared to the bond length, what is the angular frequency of the rotation?

A. 0.7×10^{15} rad s^{-1}
B. 1.4×10^{15} rad s^{-1}
C. 2.8×10^{15} rad s^{-1}
D. 5.5×10^{15} rad s^{-1}
E. 11×10^{15} rad s^{-1}

23. Simplifying Thomson's plum pudding model, consider a sphere Au with radius, $r = 1.44\times10^{-10}$ m, charge 79e uniformly distributed within the sphere and a point charge He with negligible radius and charge 2e. Considering **only** electrostatics, how much kinetic energy does He need to have initially, when it was far away, in order to just pass through Au in a head-on collision?

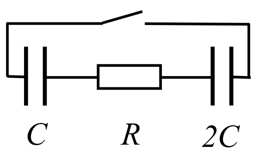
A. 1.0 keV
B. 1.2 keV
C. 2.4 keV
D. 3.6 keV
E. 4.7 keV

24. A star has twice the temperature as the sun and produces 1000 times more power than the sun. What is its radius?

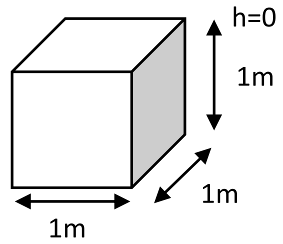
A. 2 r_s
B. 4 r_s
C. 8 r_s
D. 16 r_s
E. 32 r_s

25. A capacitance C is **initially** charged to voltage V (i.e. the potential difference across its terminals is V) with charge Q. The energy stored in the capacitor is initially E. It is connected via a resistance R to another capacitor with capacitance 2C. What is the final energy stored in the two capacitors after a long time t?

A. $E/3$
B. $E/2$
C. E
D. $E - \frac{1}{2}\frac{V^2}{R}t$
E. $E - \frac{1}{8}\frac{V^2}{R}t$



26. A container in the shape of a cube with dimensions 1 m x 1 m x 1 m is filled with water (on the surface of the earth). Which statement about the pressure at the bottom of the cube is **most complete** and **correct**?

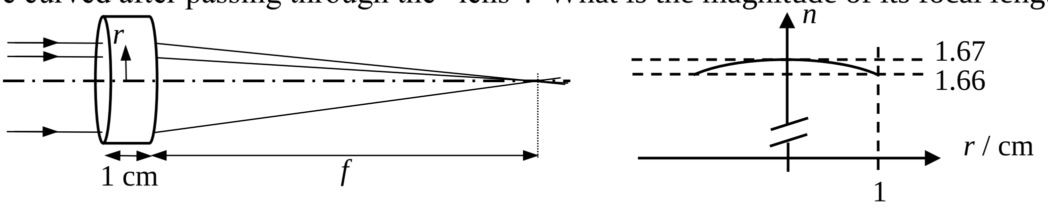


A. The pressure due to the water is 9800 Pa downwards acting in the center of the bottom surface.
B. The pressure due to the water is 9800 Pa upwards acting in the center of the bottom surface.
C. The pressure due to the water is 9800 Pa downwards.
D. The pressure due to the water is 9800 Pa.
E. The pressure due to the water is -9800 Pa downwards.

27. Which of the following "forces" is **conceptually** different from the others in classical mechanics?
A. Magnetic force
B. Gravitational force
C. Elastic spring force
D. Frictional force
E. Centripetal force

28. A photomultiplier consist of a cathode and anode and ten intermediate electrodes called dynodes in a vacuum tube. When an electron from the previous electrode hits a dynode, it immediately "knocks out" a few electrons with negligible starting velocity. The potential difference between each pair of electrodes is 125 V so that the total potential difference across the cathode and anode is 1375 V. Assuming that when a photon falls on the cathode, an electron is immediately emitted and the distance between each pair of electrodes is 1 cm, what is the time between light falling on the photocathode and a current being detected at the anode?
A. 0.33 ns
B. 0.37 ns
C. 30 ns
D. 33 ns
E. 37 ns

29. A cylinder with flat ends has radius 1 cm and length 1 cm. The cylinder is used as a lens as shown below. Its refractive index varies from the center to radius according to the formula $n = 1.67 - 0.01r^2$, where r is the distance from the center in **cm**. Since the refractive index is highest at the center, it is expected that the light wavefronts are curved after passing through the "lens". What is the magnitude of its focal length?



A. 50 cm
B. 80 cm
C. 100 cm
D. 160 cm
E. Infinite

30. A 20 cm diameter, 50 cm focal length curved mirror may be used to set fire to wood by simply focusing the sunlight onto the wood. What is the maximum intensity (power/area) at the wood? You may assume the sun is **big** and hot and the sky is clear.
A. 1.4×10^5 W m^{-2}
B. 2.6×10^5 W m^{-2}
C. 5.1×10^5 W m^{-2}
D. 1.2×10^6 W m^{-2}
E. 2.5×10^6 W m^{-2}

31. A free electron oscillates in an oscillating electromagnetic wave with electric field amplitude E_0, magnetic field amplitude B_0 and frequency f. What is the electron's maximum KE?

A. $\frac{1}{8m_e}\left(\frac{eE_0}{\pi f}\right)^2$

B. $\frac{1}{4}\varepsilon_0 E_0^2\left(\frac{c}{f}\right)^3$

C. $\frac{1}{2}m_e\left(\frac{E_0}{B_0}\right)^2$

D. $m_e f^2 E_0 B_0$

E. $2m_e(\pi f E_0)^2 c$

32. A uniform current density **j** (units of A m^{-2}) flows along a long cylinder of plasma of length l and radius r. A constant uniform magnetic field **B** is applied in the same direction as the current density along the length of the cylinder. The magnitude of <u>magnetic pressure</u> acting on the curved surface of the cylinder of plasma is **proportional** to:

A. $|\mathbf{B}||\mathbf{j}|\pi r^2 l$

B. $\frac{|\mathbf{B}|^2}{2\mu_0}$

C. $\frac{\mu_0}{8}(|\mathbf{j}|r)^2$

D. $|\mathbf{B}||\mathbf{j}|2\pi^2 r^3$

E. 0

33. For X-rays with photon energy much higher than the binding energy of electrons in a metal, the electrons may behave as "free" electrons in a plasma. The refractive index of a plasma is given by $n = \sqrt{1 - \frac{n_e e^2}{\varepsilon_0 m_e \omega^2}}$. Where n_e is the electron density, ω is the angular frequency of the x-rays. X-rays with 12.4 keV photon energy are **Totally Externally Reflected** off gold $^{197}_{79}Au$ with a critical angle $\theta_{crit} = 0.351^o$ from the **mirror's surface**. What fraction of the electrons in gold behave as "free" electrons for total external reflection?

Additional information: The density of gold is 19,300 kg m^{-3}. It takes about 81 keV to remove the electrons from the innermost shell of gold. There is 1 conduction electron per atom of gold.

A. 0.9

B. 0.4

C. 2.5×10^{-2}

D. 1.2×10^{-2}

E. 1.1×10^{-2}

34. Consider a 3 m tall house 10 m by 10 m in Korea, made of wood with average conductivity of 0.14 W m^{-1} K^{-1} and thickness 5 cm (including the roof and the floor). Assume that the outside temperature is 273.15 K (including under the floor), the inside temperature (except for the floor) is kept at 293.15 K. Hot water is pumped through a radiator the same area as the floor in good thermal contact with the floor. Assume that the black body radiator only radiates heat upwards and there are no other heat sources in the house. What temperature should the floor be at?

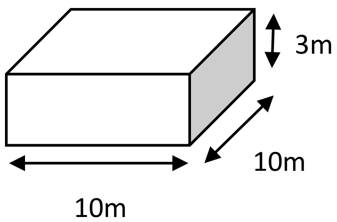
A. 313 K

B. 321 K

C. 335 K

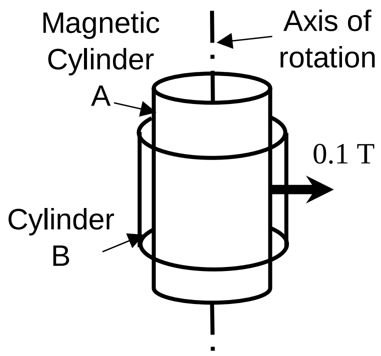
D. 342 K

E. 351 K



35. Two coaxial cylinders, A and B may be rotated on the axis as shown in the figure. The inner non-conducting cylinder A is magnetized such that a 0.1 T magnetic field points uniformly outwards through the curved surface of conducting but non-magnetic cylinder B with radius 5 cm and length 4 cm. The potential difference between the top and bottom of cylinder B may be measured using a stationary voltmeter.
Consider the following cases:

I - cylinder B rotates at 120 rpm, cylinder A is stationary,
II - cylinder A and B rotate at 120 rpm together,
III - cylinder B rotates at 120 rpm, cylinder A rotates at 120 rpm in the opposite way,
IV - cylinder A rotates at 120 rpm, cylinder B is stationary,



Which is true?

A. Case III produces the largest potential difference and all other cases produce lower potential differences.
B. Cases I and II produce the same potential difference.
C. Cases I and IV produce the same potential difference.
D. Case II produces zero potential difference.
E. Not (all or one) but (some or none) of the above is true.

36. The Voyager spacecraft carried a small amount of initially pure ${}^{238}_{92}\text{U}$ on the covers of their golden records to facilitate dating. Part of the uranium series is shown below with the half-life labelled. What are the ratios of the number of ${}^{234}_{92}\text{U}$ to ${}^{238}_{92}\text{U}$ after 10^5 years and 2×10^6 years respectively?

$$ {}^{238}_{92}\text{U} \xrightarrow{4.468\times10^9\text{ y}} {}^{234}_{90}\text{Th} \xrightarrow{24.1\text{ d}} {}^{234m}_{91}\text{Pa} \xrightarrow{<7\text{ h}} {}^{234}_{92}\text{U} \xrightarrow{2.445\times10^5\text{ y}} {}^{230}_{90}\text{Th} \xrightarrow{7.7\times10^4\text{ y}} {}^{226}_{88}\text{Ra} \ \ldots. $$

A. 1.4×10^{-5}, 3.8×10^{-5}
B. 1.4×10^{-5}, 5.5×10^{-5}
C. 1.8×10^{-5}, 3.8×10^{-5}
D. 1.8×10^{-5}, 5.5×10^{-5}
E. 1.8×10^{-5}, 3.1×10^{-4}

37. Two tungsten filament bulbs are connected in parallel to a 12 V battery. In this configuration, **one bulb** consumes 10 W of power and the other 5W. What is the amount of power **supplied** P if the two bulbs are connected in series to the 12 V battery?

A. $P < 5$ W
B. 5 W $\leq P <$ 10 W
C. 10 W $\leq P <$ 15 W
D. 15 W $\leq P <$ 20 W
E. $P \geq$ 20 W

38. A type of helicopter can hover if its mechanical power output is P. If an exact ½-scale replica (in all linear dimensions) of the helicopter is made using the same material, what is the mechanical power P' needed for the helicopter to hover?

A. $2^{-3.5} P$
B. $2^{-3} P$
C. P
D. $2^{3} P$
E. $2^{3.5} P$

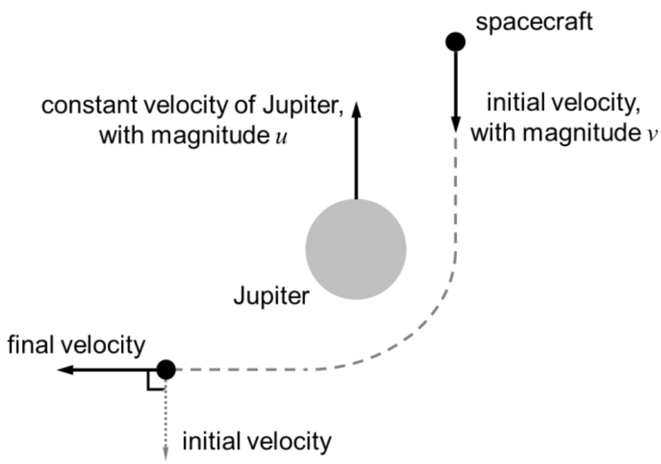
39. The volumetric thermal expansion coefficient of iron is 35.4×10^{-6} K^{-1}, and its specific heat capacity is 0.450 kJ / (kg K). Assume these quantities are constant at all relevant temperatures.
A cubic block of iron with side length 0.100 m and mass 7.87 kg is placed on a flat, unmoving, completely insulating table. 1 kJ of thermal energy is supplied to this iron block. Let the final temperature of this iron block be *T*.
A second block of iron, identical to the first with the same initial temperature, is hung by an inextensible, completely insulating string from a fixed point on the wall. 1 kJ of thermal energy is also supplied to this iron block. Let the final temperature of the second iron block be *T'*. Calculate *T* – *T'*.

A. – 14.5 nK
B. – 7.26 nK
C. 0
D. + 7.26 nK
E. + 14.5 nK

40. A small tennis ball with mass m sits atop a large basketball with mass *M*, with $M \gg m$. The balls are released from rest, with the bottom of the basketball at a height h above the ground. The diameter of the tennis ball is d and that of the basketball is *D*, with $D \gg d \approx 0$. To what height does the tennis ball bounce above the ground? Assume all collisions are elastic.

A. $D + h$
B. $D + 4h$
C. $D + 8h$
D. $D + 9h$
E. There is insufficient information.

41. In a 'gravitational slingshot' maneuver, a spacecraft uses the gravity of a large planet to change its path and increase its speed. Such a maneuver can be analyzed as a collision.
A spacecraft is initially headed at speed *v* towards Jupiter, which is moving at a speed *u* in the opposite direction. The final velocity of the spacecraft is perpendicular to the initial velocity of the spacecraft. Assuming that $u = v$, what is the final speed of the spacecraft in terms of *v*?

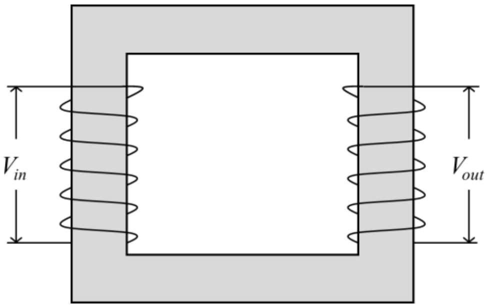


A. $v / 2$
B. v
C. $v\sqrt{2}$
D. $v\sqrt{3}$
E. $2v$

42. A mass *M*, with initial speed *V*, collides elastically with a stationary mass $m = M/2$. Find the maximum angle of deflection of the mass *M*.

A. 180°
B. 120°
C. 30°
D. 0
E. There is insufficient information to tell.

43. Consider the alternating-current transformer above. Which of the following statements gives the correct explanation and phase difference between V_{in} and V_{out}?



A. By Faraday's Law, phase difference = 0 (i.e. V_{in} and V_{out} are in phase).
B. By Faraday and Lenz's law, phase difference = 45°.
C. By analogy to simple harmonic motion, phase difference = 90°.
D. By Fleming's Left hand rule, phase difference = 135°.
E. By Lenz's Law, phase difference = 180° (i.e. V_{in} and V_{out} are in anti-phase).

44. An initially stationary polonium-214 nucleus undergoes alpha-decay to give two products:

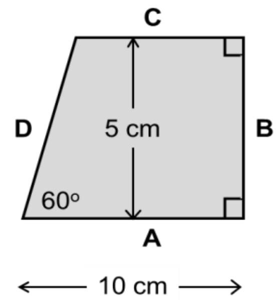
$$^{214}\text{Po} \rightarrow {}^{210}\text{Pb} + {}^{4}\text{He}.$$

Given that the total kinetic energy of the products is Q = 7.83 MeV, the kinetic energy of the alpha-particle (^{4}He) is E = (210/214) Q = 7.68 MeV. This can be found by applying the two equations of conservation of energy and conservation of momentum to solve for two variables (velocities of ^{210}Pb and ^{4}He).
An initially stationary phosphorus-32 nucleus undergoes beta-decay to give three products:

$$^{32}\text{P} \rightarrow {}^{32}\text{S} + {}^{0}\text{e}^{-} + \bar{\nu}.$$

Given that the total kinetic energy of the products is Q = 1.71 MeV, what is the kinetic energy of the beta-particle ($^{0}\text{e}^{-}$)?
A. 0
B. 1.49 MeV
C. 1.52 MeV
D. 1.71 MeV (i.e. Q)
E. There is insufficient information to tell.

45. On which of the following faces should the uniform prism (whose cross-section is shown below) be placed so that it would have to be tilted by the largest angle before toppling? (The aim is to maximise the threshold angle, beyond which the prism topples. A prism is a 3-dimensional solid with a uniform cross-section.)
A-D. (As shown.)
E. There is no single face with the largest threshold angle (i.e. more than one face have the same threshold angle).

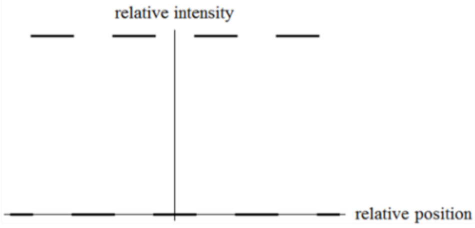


The diagram is not to scale.

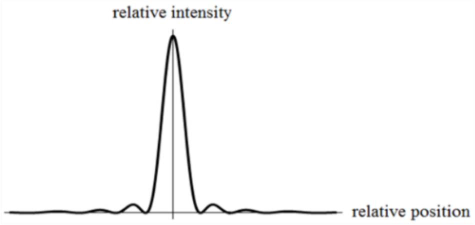
46. Moist air moves adiabatically across a mountain range. At the ground level, the atmospheric pressure is 100 kPa and the temperature is 20°C. Clouds begin to form at a height of 1410 m above the ground, where the pressure is 84.5 kPa. Find the temperature of the air at this height. (Assume that moist air behaves like a diatomic ideal gas, with $\gamma = c_p / c_v = 1.4$.)
A. 0°C
B. 2°C
C. 4°C
D. 6°C
E. 8°C

47. What is the correct graph of intensity against position for a far-field 4-slit interference setup?

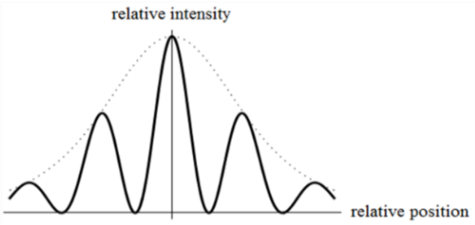
A



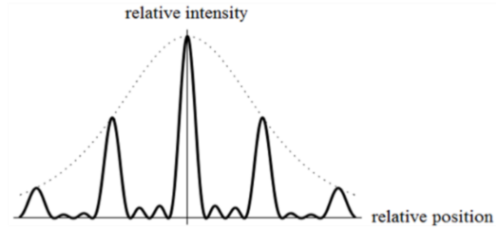
B



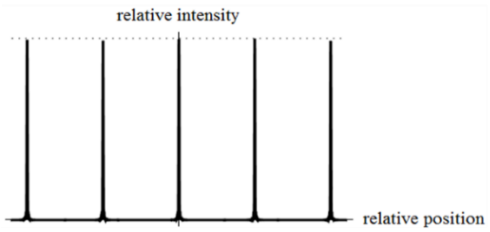
C



D

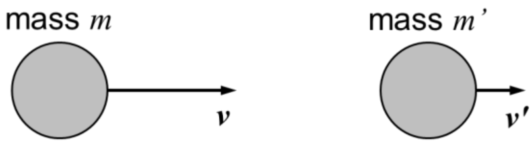


E



The axes are not to scale.

48. A mass m collides elastically with another mass m'. The velocity of mass m is $\mathbf{v}$ and that of mass m' is $\mathbf{v'}$. Both masses are moving at relativistic speeds.
Which quantity is conserved before and after the collision?
($|\mathbf{v}| \equiv v$; $|\mathbf{v'}| \equiv v'$)



A. $m\mathbf{v} + m'\mathbf{v'}$
B. $(m\mathbf{v} + m'\mathbf{v'}) / \sqrt{(1 - v^2/c^2)}$
C. $m / \sqrt{(c^2 - v^2)} + m' / \sqrt{(c^2 - v'^2)}$
D. $mv / \sqrt{(1 - v^2)} + m'v' / \sqrt{(1 - v'^2)}$
E. $|\mathbf{v} - \mathbf{v'}|$

49. A long, hard train collides with a small fly. Assume the mass of the fly is negligible compared to the mass of the train. The train and the fly were initially moving towards each other with the same magnitude of velocity. When they collide, the train and fly stick to each other and finally travel with the same velocity as each other. Which of the following statements is most true in relation to the above?
A. During the collision the velocity of the fly changes direction instantaneously to that of the train.
B. During the collision the fly stops moving at some point in time since the velocity changes in direction.
C. Since the velocity of the fly must be zero at some time during the collision and it is attached to the train, then the train also has zero velocity at that time.
D. After the collision the fly must have gained momentum from the train.
E. The train must have exerted a large force on the fly due to its large momentum. The force exerted on the fly is proportional to the momentum of the train.

50. Two long parallel wires are distance x away from each other. One wire CC carries a constant current I. At time $t = 0$, the current is immediately switched on in the other wire PC for time duration $\Delta t = x / c$ before it is switched off. Which of the following is most true and detailed in relation to the above situation?
A. When the current is switched on in PC, CC immediately experiences a magnetic force acting on it.
B. When the current is switched on in PC, PC immediately experiences a magnetic force acting on it.
C. Due to Newton's 3rd law, CC & PC experience equal and opposite magnetic forces at the same time.
D. Due to Einstein's special relativity, CC & PC experience equal and opposite forces at the same time.
E. Due to Heisenberg's uncertainty principle, we cannot be certain that CC or PC experiences a magnetic force because we are not certain if their momentum has changed.