# Harvard Undergraduate Science Olympiad India
# 2024 Open Round
# Physics (7th-8th Grade) Key

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

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

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

**Allowed Materials:**

You must bring:

- #2 pencil
- Eraser

You are allowed:

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

You may not bring

- Smart watch
- Books or notes
- Electronic devices

1. Which of the following is the correct expression for the kinetic energy of an object of mass *m* moving with speed *v*?

    a. $\frac{mv}{2}$
    b. $mv$
    c. $\frac{mv^2}{2}$
    d. $mv^2$
    e. $m^2v^2$

For questions 2-5, assume that the rightwards direction is positive, and the leftwards direction is negative.

2. A race car has an acceleration of 14 $m/s^2$. If the car starts with a velocity of 7 $m/s$, how long will it take for the car to reach 70 $m/s$?

    a. 2 seconds
    b. 4.5 seconds
    c. 5 seconds
    d. 10 seconds
    e. 1 minute, 3 seconds

3. Once the driver reaches 70 $m/s$, they stop accelerating. They then throw a ball backwards with a velocity of -15 $m/s$ relative to the car. How fast is the ball moving relative to the ground?

    a. -70 $m/s$
    b. -15 $m/s$
    c. 0 $m/s$
    d. 15 $m/s$
    e. 55 $m/s$

4. The race car decelerates at a constant rate until it reaches 50 $m/s$. If this process takes 5 seconds, what is the acceleration of the car?

    a. -20 $m/s^2$
    b. -5 $m/s^2$
    c. -4 $m/s^2$
    d. 0 $m/s^2$
    e. 5 $m/s^2$

5. After driving at $50\ m/s$ for awhile, the driver hits the breaks, and starts decelerating with a rate of -8 $m/s^2$. How far away is the point where the car stops from where the car started breaking?

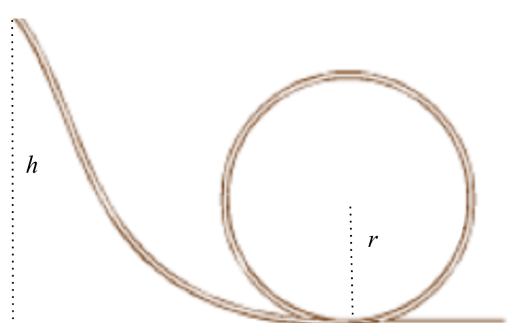
    a. $40\ m$
    b. $156.25\ m$
    c. $250\ m$
    d. $312.5\ m$
    e. $2500\ m$

6. Which of the following is the correct expression for the force between two particles with an equal charge of $q$, separated by a distance of $r$?

    a. $\frac{kq}{r}$
    b. $kq^2r^2$
    c. $\frac{kr^2}{q^2}$
    d. $\frac{kq}{r^2}$
    e. $\frac{kq^2}{r^2}$

7. You have a toy plane with a mass of 0.7 kg attached to a rope. You spin the plane in a circle with a radius of 20 cm. If the speed of the plane is 8 m/s, what is the force in the rope?

    a. 5.6 N
    b. 22.4 N
    c. 112 N
    d. 224 N
    e. 320 N




(Rollercoaster for problems 8-10)

8. You're riding on a roller coaster. Starting from a peak, you drop a height of *h*, and go into a circular loop with radius *r*. What is your speed at the bottom of the loop?

   a. $\frac{h^2}{r}$
   b. $hr$
   c. $\sqrt{gr}$
   d. $\sqrt{\frac{gh^2}{r}}$
   e. $\sqrt{2gh}$

9. What is the force from the track onto the car of mass *m* of the rollercoaster when the car is halfway up the track? (The car is directly to the right of the center of the loop)

   a. $mg$
   b. $\frac{mgh}{r}$
   c. $\frac{2mgh}{r}$
   d. $\frac{2mg(h-r)}{r}$
   e. $\frac{\sqrt{2}mg(h-r)}{r}$

10. What is the minimum value of *h* needed for the cart to reach the top of the loop?

    a. $r$
    b. $\sqrt{2}r$
    c. $2r$
    d. $\frac{5r}{2}$
    e. $5r$

11. What is the equivalent resistance of 11.0 Ω, 15.5 Ω, and 36.3 Ω resistors all connected in series?

    a. 5.47 Ω
    b. 9.80 Ω
    c. 31.8 Ω
    d. 62.8 Ω
    e. 6190 Ω

12. What is the equivalent resistance of 144 Ω, 176 Ω, and 39.0 Ω resistors all connected in parallel?

    a. 26.1 Ω
    b. 38.8 Ω
    c. 120 Ω
    d. 359 Ω
    e. 709 Ω

13. A planet of $6.39*10^{23}$ kg and a speed of $2.41*10^4$ m/s smashes into a planet at rest with a mass of $5.97*10^{24}$. During the collision, the two planets form one larger body. What is the speed of this new planet?

    a. $2.33*10^3$ m/s
    b. $2.89*10^3$ m/s
    c. $1.01*10^4$ m/s
    d. $1.21*10^4$ m/s
    e. $1.40*10^4$ m/s

14. What are the two types of mass that are set to be equal by the equivalence principle?

    a. Gravitational mass and frictional mass
    b. Gravitational mass and inertial mass
    c. Critical mass and inertial mass
    d. Critical mass and baryonic mass
    e. Baryonic mass and fermionic mass

15. Which of the following is not a fictitious force?

    a. Lorentz Force
    b. Centrifugal Force
    c. Coriolis Force
    d. Euler Force
    e. All of the above forces are fictitious forces

16. A simple pendulum has a period of 3 seconds. If you increase the length of the pendulum by a factor of 3, and increase the mass by a factor of 2, what will the period of the new pendulum be?

    a. 1.73 s
    b. 3.67 s
    c. 5.20 s
    d. 7.35 s
    e. 10.4 s

17. A planet has an even mass distribution, and a gravitational acceleration at the surface given by *g*. If the radius of the planet is *R*, what is the gravitational acceleration caused by the planet at a distance of 2*R*?

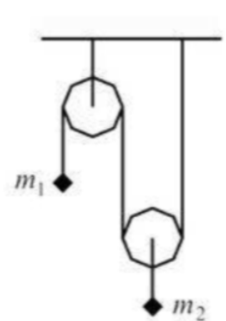
a. $\frac{g}{4}$
b. $\frac{g}{2}$
c. $g$
d. $2g$
e. $4g$

18. A planet has an even mass distribution, and a gravitational acceleration at the surface given by *g*. If the radius of the planet is *R*, what is the gravitational acceleration inside the planet at a distance of *R/2*?

a. $\frac{g}{4}$
b. $\frac{g}{2}$
c. $g$
d. $2g$
e. $4g$

19. What is the force felt by a stationary electron in a magnetic field with field strength 0.01T?

a. $1.60*10^{-2}$ N
b. $1.00*10^{-2}$ N
c. $6.25*10^{-3}$ N
d. $1.60*10^{-21}$ N
e. 0.00 N




(An Atwood Machine)

20. If the pulleys in the above system are massless, what are the accelerations of $m_1$ and $m_2$ respectively? Take the downwards direction to be positive.

a. $m_1$: $\frac{2m_1 - 2m_2}{2m_1 + m_2} g$, $m_2$: $\frac{-m_1 + m_2}{2m_1 + m_2} g$
b. $m_1$: $\frac{4m_1 - 2m_2}{4m_1 + m_2} g$, $m_2$: $\frac{-2m_1 + m_2}{4m_1 + m_2} g$
c. $m_1$: $\frac{4m_1 + 2m_2}{4m_1 + m_2} g$, $m_2$: $\frac{m_1 + m_2}{4m_1 + m_2} g$
d. $m_1$: $\frac{-2m_1 + m_2}{m_1 - 2m_2} g$, $m_2$: $\frac{2m_1 - m_2}{m_1 - 2m_2} g$
e. $m_1$: $\frac{m_1 - 2m_2}{m_1 + m_2} g$, $m_2$: $\frac{-m_1 + 2m_2}{2m_1 + 2m_2} g$

21. What is the value of the electric field a distance of $d$ away from an infinite sheet of charge with a charge density of $\sigma$?

a. $\sigma d$
b. $\frac{\sigma \varepsilon_0}{2d}$
c. $\frac{\sigma}{\varepsilon_0 d^2}$
d. $\sigma \varepsilon_0$
e. $\frac{\sigma}{2\varepsilon_0}$

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

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

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

a. $\mu^2 \sqrt{\frac{g}{R}}$

b. $\sqrt{\frac{\mu g}{R}}$

c. $\sqrt{\frac{g}{\mu R}}$

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

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

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

a. $M$: $\frac{v}{6}$, $2M$: $\frac{v}{6}$, $3M$: $\frac{v}{6}$

b. $M$: $\frac{v}{6}$, $2M$: $\frac{v}{3}$, $3M$: $\frac{v}{2}$

c. $M$: $\frac{-v}{3}$, $2M$: $\frac{-2v}{15}$, $3M$: $\frac{3v}{15}$

d. $M$: $\frac{-v}{3}$, $2M$: $\frac{-2v}{15}$, $3M$: $\frac{8v}{15}$

e. $M$: $\frac{-v}{6}$, $2M$: $\frac{-7v}{30}$, $3M$: $\frac{49v}{90}$

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

a. 0.028 V

b. 1.100 V

c. 2.750 V

d. 10.10 V

e. 1100. V

26. A cylindrical human being is spinning around their central axis (the axis normal to both ends of the cylinder) with an angular velocity of ω. This person has height *h*, radius *r*, and an evenly distributed mass of *M*. What is the rotational kinetic energy of this person?

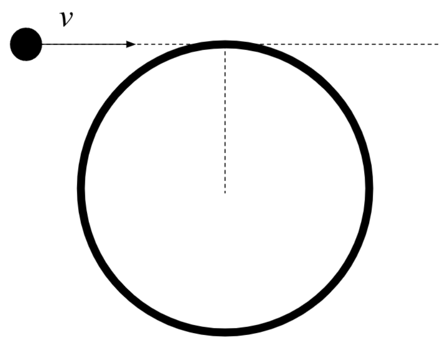
a. $\frac{M\omega^2 h^2}{2}$

b. $\frac{M\omega^2 r^2}{2}$

c. $\frac{M\omega^2 rh}{4}$

d. $\frac{M\omega^2 r^2}{24}$

e. $\frac{M\omega^2 r^2}{4}$




(Diagram For Problems 27-28)

27. A ball of mass *m* is flying towards the cylindrical human from Question 26 with speed *v*. If the cylinder is rotating counterclockwise, what is the *v* necessary to stop the person from rotating, assuming that the person catches the ball?

a. $r\omega$
b. $\frac{mr\omega}{M}$
c. $\frac{Mr\omega}{4m}$
d. $\frac{Mr\omega}{2m}$
e. $\frac{Mr\omega}{m}$

28. How much energy is lost when the person catches the ball?

a. $\frac{mv^2+M\omega^2r^2}{2}$
b. $\frac{2mv^2+M\omega^2r^2}{4}$
c. $\frac{mv^2+M\omega^2r^2}{24}$
d. $\frac{Mv^2+2m\omega^2r^2}{4}$
e. $\frac{2mv^2h^2+m\omega^2r^4}{4r^2}$

29. A block of wood with mass *M* is dangling from a rope of length *l*. A bullet with mass *m* is shot into the block of wood, causing it to swing up by a certain angle θ. Given these parameters, what is the initial speed of the bullet, assuming the initial path of the bullet is perpendicular to the pendulum?

a. $\frac{M}{m}\sqrt{2gl}$
b. $\sqrt{2gl(1 - sin\theta)}$

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

30. An electron inside a region with a magnetic field is traveling in a circle, with a radius of 8.0 microns, and a speed of 3000 m/s. What is the strength of the magnetic field?

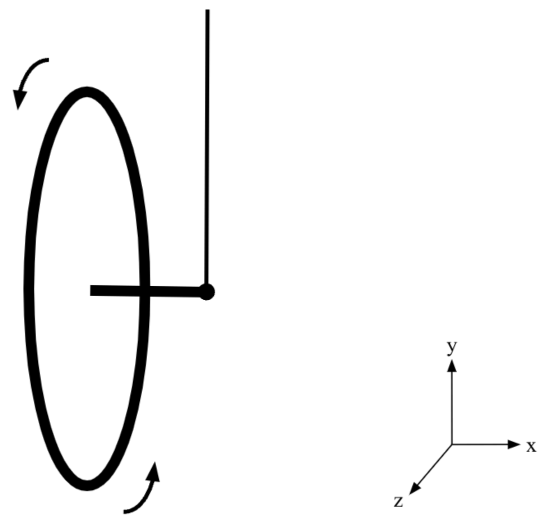
    a. $2.1*10^{-3}$ T
    b. $2.4*10^{-3}$ T
    c. $2.7*10^{-2}$ T
    d. $3.5*10^{-2}$ T
    e. $6.1*10^{-2}$ T

31. A metal ball with a radius of 5 cm has 4.0 μC of charge on it. What is the value of the electric potential at a point 2 meters away from the center of the ball? Assume that the electric potential is 0 at an infinite distance away.

    a. 0.07192 V
    b. 57.54 V
    c. 17980 V
    d. 36000 V
    e. 719200 V

32. For the same setup given in question 31, what is the electric potential inside the ball, at a point 2 cm away from the center?

    a. 57.54 V
    b. 719200 V
    c. 1798000 V
    d. 2877000 V
    e. 89900000 V



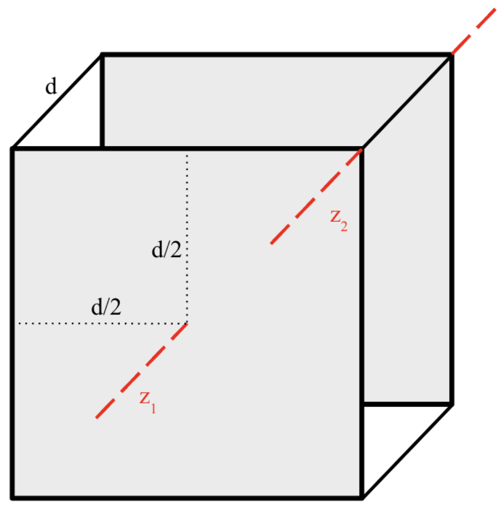

(Diagram for Problems 33-34)

33. Your physics teacher shows you a bicycle wheel that spins around an axle which is connected to a rope. At the moment shown in the diagram, the wheel lies in the y-z plane. What is the direction of the angular momentum of the wheel at this moment in time?

    a. +x
    b. -x
    c. +y
    d. -y
    e. +z

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

    a. The wheel will keep rotating, but the axle will not move
    b. The wheel and axle will drop down, and the wheel will stop rotating
    c. The wheel will keep rotating, and the axle will swing back and forth
    d. As seen from above, the axle and wheel will rotate clockwise
    e. As seen from above, the axle and wheel will rotate counterclockwise




(Diagram for Problems 35-36)

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

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

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

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

37. An AC circuit has a voltage source that oscillates with a frequency of 1/2π kHz. A 4Ω resistor, a 7mH inductor, and 0.25 mF capacitor are connected in series. What is the total impedance of this circuit?

    a. 1.1Ω

b. 5.0Ω
c. 7.1Ω
d. 11.7Ω
e. 30.2Ω

38. You construct a frictionless ramp with an angle $\theta$. You place a block of mass $M$ on the ramp, and then place a ball (not hollow) with mass $m$ and radius $r$ on top of the block. There is a coefficient of friction of $\mu$ between the block and the ball. Assuming that the ball doesn't slip, what is the acceleration of the ball relative to the block?

a. $g \sin \theta$
b. $\frac{2g\sin\theta}{5}$
c. $\frac{5g\sin\theta}{2}$
d. $\frac{5g\sin\theta}{3}$
e. $\frac{5g\sin\theta}{7}$

39. Given the same setup as problem 38, what is the acceleration of the ball with respect to the ramp?

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

40. A spaceship of mass 400000 kg is employing a new type of propulsion. Electrons are accelerated from rest across a potential difference of 12000V. Considering only classical physics, and ignoring the change in mass of the spaceship due to the loss of electrons, how many electrons need to be accelerated in order to accelerate the spaceship from rest to 0.01% of the speed of light? Also assume that the speed of the electrons is significantly faster than the speed of the spaceship.

a. $1.69*10^{22}$ electrons
b. $5.13*10^{31}$ electrons
c. $2.03*10^{32}$ electrons
d. $5.13*10^{33}$ electrons
e. $2.03*10^{34}$ electrons

# Important Constants

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