

NEET (UG) · JEE MAIN · JEE ADVANCED

SELECTED PROBLEMS IN PHYSICS

VOLUME 1

159 hand-picked problems with complete, step-by-step solutions

Kinematics · Laws of Motion · Circular Motion · Work and Energy · Momentum · Rotation · Gravitation and Oscillations · Fluids · Heat and Thermodynamics · Waves and Sound · Ray Optics · Electrostatics · Capacitors, Circuits and Magnetism

ANANT SHUKLA & TEAM

Master Testing Agency

Selected Problems in Physics

Volume 1

NEET (UG) · JEE Main · JEE Advanced

Anant Shukla and Team

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The problems in this book were chosen from the classic themes that appear again and again in competitive physics. Every problem has been rewritten in our own words, many with new data, and every solution is our own. Every numerical answer has been worked out a second time by computer from the data in the question; the book is not printed if any of these checks fails. If you still find a mistake, please write to us.

NEET (UG), JEE (Main) and JEE (Advanced) are conducted by the National Testing Agency and the Indian Institutes of Technology. This book is an independent study aid and is not connected with any of them.

Preface

Physics is learnt by solving problems. Not a thousand easy ones, but a few hundred good ones – problems that make you draw a clean figure, choose the right frame, write the right equations and check your result.

This book collects 159 such problems. They range from questions a careful NEET (UG) aspirant can solve in a few minutes to problems at the top end of JEE Advanced. Each problem carries a small tag: **NEET**, **JEE Main** or **JEE Adv**. The tag shows the examination for which the problem is most useful; it is not a promise that the problem is easy or hard.

Every chapter has three parts:

- **Problems** – try every one of them yourself, on paper, before turning the page;
- **Answer Key** – the final answers in one place, so you can check quickly;
- **Worked Solutions** – complete solutions, step by step, with the physical idea stated first.

When you are stuck, read only the first line or two of the solution – the idea – and then try again. A problem you finish yourself after a hint teaches far more than a solution you read to the end.

We thank our students, whose questions over many years shaped this collection, and we wish every reader success.

Anant Shukla and Team

Values and conventions used in this book

Acceleration due to gravity	$g = 10 \text{ m s}^{-2}$ unless stated otherwise
Coulomb constant	$k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$
Gas constant	$R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$
Density of water	1000 kg m^{-3}
Sign convention in optics	Cartesian: distances measured from the pole or the optical centre, positive in the direction of the incident light.

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CHAPTER 1

Kinematics and Constraint Relations

Most of these problems need no force at all. Fix the geometry first: write the coordinates of the moving points, use the fact that strings do not stretch and rods do not bend, and differentiate. Choosing a clever frame of reference often turns a hard problem into a one-line one.

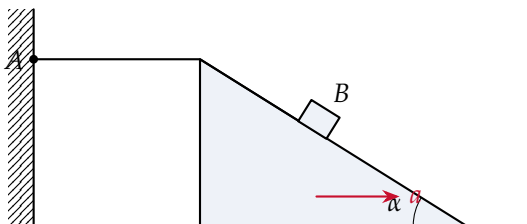
Problems

Problem 1.1

JEE Adv

A light inextensible rope lies on a wedge whose sloping face makes an angle α with the horizontal. One end of the rope is tied to a wall at A ; from A the rope runs horizontally to the top edge of the wedge and then down the sloping face, where a small load B is tied to its other end. The wedge starts moving away from the wall with a constant acceleration a .

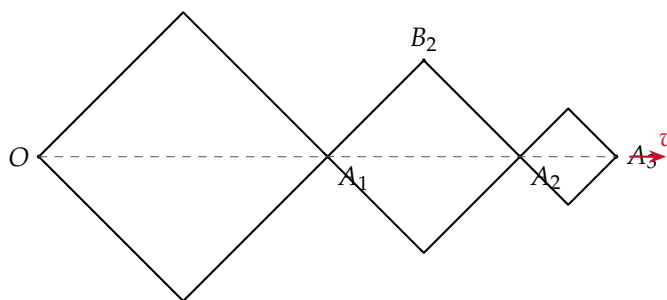
- (a) Find the acceleration of the load relative to the ground.
- (b) Evaluate it for $a = 3 \text{ m s}^{-2}$ and $\alpha = 60^\circ$.



Problem 1.2

JEE Adv

A hinged frame is made of three rhombuses placed one after another along a horizontal line. The sides of the rhombuses are in the ratio 3 : 2 : 1. The frame is built so that the sides of neighbouring rhombuses lie along the same straight lines; therefore all three rhombuses always have the same angles. The left vertex O of the first rhombus is fixed, and the far vertex A_3 of the third rhombus is pulled along the line OA_3 with speed v . Find the speeds of the vertices A_1 and A_2 and of the upper vertex B_2 of the middle rhombus at the instant when all the angles of the rhombuses are 90° .



Problem 1.3

NEET

Two thin paper discs are fixed on a common axle, 0.50 m apart. The axle turns at 1500 revolutions per minute. A bullet flies parallel to the axle and pierces both discs. The hole in the second disc is found to be turned through 12° relative to the hole in the first. Find the speed of the bullet, assuming it is the largest value that fits these data.

Problem 1.4

JEE Adv

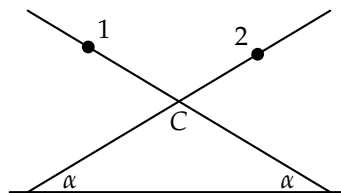
A particle moves with constant angular speed ω on a circle of radius R in the xy -plane. Seen from a frame that moves with constant velocity along the z -axis, the particle moves on a helix of constant pitch h . Find the radius of curvature of this helical path.

- (a) R (b) $R + \frac{h^2}{4\pi^2 R}$
 (c) $\sqrt{R^2 + \frac{h^2}{4\pi^2}}$ (d) It cannot be found from these data

Problem 1.5

JEE Adv

Two smooth straight slides lie in the same vertical plane, each inclined at an angle α to the horizontal but sloping in opposite directions, so that they cross at a point C (the slides are side by side, so balls on them never collide). A ball is placed on each slide above C and both balls are released at the same moment. The first ball reaches the crossing point after a time t_1 , the second after a time t_2 . At what moment is the distance between the balls the smallest, and what is this smallest distance?

**Problem 1.6**

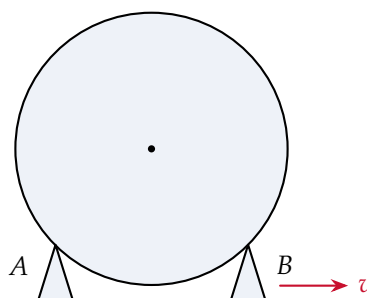
JEE Main

A gun on the sea shore, fired at the elevation that gives the greatest range, sends a shell 2.0 km. The same gun is mounted on a cliff 60 m above the sea and fired with the same muzzle speed at the same elevation. By what percentage does the range on the sea increase? Neglect air resistance.

Problem 1.7

JEE Adv

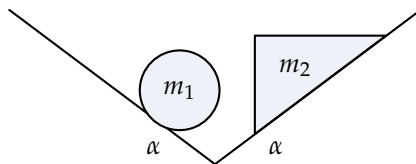
A uniform smooth cylinder of mass m and radius r rests on two supports A and B at the same height. Support A is fixed; support B is pulled out from under the cylinder with a constant horizontal speed v . Find the force with which the cylinder presses on A at the moment when $AB = r\sqrt{2}$. Friction is negligible. Evaluate it for $m = 2 \text{ kg}$, $r = 0.20 \text{ m}$, $v = 1.0 \text{ m s}^{-1}$.



Problem 1.8

JEE Adv

A smooth V-shaped trough is formed by two planes, each inclined at $\alpha = 37^\circ$ to the horizontal. A cylinder of mass $m_1 = 3$ kg lies on the left plane and a block of mass $m_2 = 1$ kg, whose face towards the cylinder is vertical, lies on the right plane. The cylinder touches this vertical face. The system is released. Find the force between the cylinder and the block, and the acceleration of each body. There is no friction anywhere.

**Answer Key**

1.1 (a) $2a \sin(\alpha/2)$, at $90^\circ - \alpha/2$ to the horizontal;
(b) 3 m s^{-2}

1.2 $v_{A1} = v/2$, $v_{A2} = 5v/6$, $v_{B2} = \sqrt{17}v/6$

1.3 375 m s^{-1}

1.4 (b) $R + h^2/(4\pi^2 R)$

1.5 $t = \sqrt{(t_1^2 + t_2^2)/2}$; $d_{\min} = \frac{1}{2}g \sin^2 \alpha |t_1^2 - t_2^2|$

1.6 about 2.9 % (range ≈ 2.06 km)

1.7 $N = \frac{mg}{\sqrt{2}} - \frac{mv^2}{2r} \approx 9.1 \text{ N}$

1.8 $N = \frac{2m_1 m_2 g \tan \alpha}{m_1 + m_2} = 11.25 \text{ N}$; $a = 3 \text{ m s}^{-2}$
along each plane

Worked Solutions**Solution 1.1**

Idea. Split the motion of the load into the motion of the wedge plus the motion of the load along the wedge.

When the wedge moves a distance x away from the wall, the horizontal part of the rope becomes longer by x . The rope does not stretch, so the part lying on the sloping face becomes shorter by x : the load moves a distance x up the slope relative to the wedge. Hence, relative to the wedge, the load has an acceleration a directed up the slope,

$$\vec{a}_{\text{rel}} = a(-\cos \alpha, \sin \alpha), \quad \vec{a}_{\text{wedge}} = a(1, 0).$$

Adding,

$$\vec{a}_B = a(1 - \cos \alpha, \sin \alpha), \quad |\vec{a}_B| = a\sqrt{(1 - \cos \alpha)^2 + \sin^2 \alpha} = a\sqrt{2(1 - \cos \alpha)} = 2a \sin \frac{\alpha}{2}.$$

(b) With $\alpha = 60^\circ$: $a_B = 2 \times 3 \times \sin 30^\circ = 3 \text{ m s}^{-2}$. Its direction makes an angle $90^\circ - \alpha/2 = 60^\circ$ with the horizontal.

Answer: (a) $2a \sin(\alpha/2)$, at $90^\circ - \alpha/2$ to the horizontal; (b) 3 m s^{-2}

Solution 1.2

Idea. Every vertex position is a fixed multiple of $\cos \theta$ or $\sin \theta$, where θ is the common half-angle; all velocities are therefore proportional to $\dot{\theta}$.

Let the sides be $3s$, $2s$, s and let θ be the angle each side makes with the line OA_3 . The horizontal diagonal of a rhombus of side ℓ is $2\ell \cos \theta$, so

$$x_{A1} = 6s \cos \theta, \quad x_{A2} = 10s \cos \theta, \quad x_{A3} = 12s \cos \theta.$$

Since the distances are all proportional to $\cos \theta$, the speeds are proportional to the distances from O :

$$v_{A1} = \frac{6}{12}v = \frac{v}{2}, \quad v_{A2} = \frac{10}{12}v = \frac{5v}{6}.$$

For B_2 : $x = 6s \cos \theta + 2s \cos \theta = 8s \cos \theta$ and $y = 2s \sin \theta$. Differentiating,

$$\dot{x} = -8s \sin \theta \dot{\theta}, \quad \dot{y} = 2s \cos \theta \dot{\theta}, \quad v = |\dot{x}_{A_3}| = 12s \sin \theta |\dot{\theta}|.$$

At the instant considered $\theta = 45^\circ$, so $\sin \theta = \cos \theta$ and

$$|\dot{x}| = \frac{8}{12}v = \frac{2v}{3}, \quad |\dot{y}| = \frac{2}{12}v = \frac{v}{6}, \quad v_{B_2} = v\sqrt{\frac{4}{9} + \frac{1}{36}} = \frac{\sqrt{17}}{6}v \approx 0.69v.$$

Answer: $v_{A_1} = v/2$, $v_{A_2} = 5v/6$, $v_{B_2} = \sqrt{17}v/6$

Solution 1.3

While the bullet travels from one disc to the other (time $t = H/v$) the axle turns through $\varphi = \omega t$. The largest speed corresponds to the smallest angle, $\varphi = 12^\circ = \pi/15$ (not $12^\circ + 360^\circ, \dots$).

$\omega = 1500 \times 2\pi/60 = 50\pi \text{ rad s}^{-1}$, so

$$v = \frac{\omega H}{\varphi} = \frac{50\pi \times 0.50}{\pi/15} = 375 \text{ m s}^{-1}.$$

In general $v = \omega H/(\varphi + 2\pi n)$, $n = 0, 1, 2, \dots$

Answer: 375 m s^{-1}

Solution 1.4

Idea. Radius of curvature $\rho = v^2/a_n$, where a_n is the component of acceleration perpendicular to the velocity.

In the moving frame the particle has the circular velocity ωR plus a constant velocity u along z . In one turn (time $2\pi/\omega$) it advances by the pitch, so $u = h\omega/2\pi$. Hence

$$v^2 = \omega^2 R^2 + \frac{h^2 \omega^2}{4\pi^2}.$$

The frame does not accelerate, so the acceleration is still $\omega^2 R$, directed towards the axis. This is perpendicular both to the circular velocity and to $\vec{u}$, so it is entirely normal: $a_n = \omega^2 R$. Therefore

$$\rho = \frac{v^2}{a_n} = R + \frac{h^2}{4\pi^2 R}.$$

Option (b). Note that the answer does not depend on ω : it is purely geometric.

Answer: (b) $R + h^2/(4\pi^2 R)$

Solution 1.5

Idea. Work in the frame of ball 1. Both balls start from rest and have constant accelerations, so the relative motion starts from rest with a constant relative acceleration: it is a straight line.

Each ball has acceleration $g \sin \alpha$ along its slide. With unit vectors $\hat{e}_1 = (\cos \alpha, -\sin \alpha)$ and $\hat{e}_2 = (-\cos \alpha, -\sin \alpha)$ along the two slides (downwards),

$$\vec{a}_2 - \vec{a}_1 = g \sin \alpha (\hat{e}_2 - \hat{e}_1) = (-2g \sin \alpha \cos \alpha, 0).$$

The relative acceleration is horizontal. So the vertical separation never changes, and the distance is least when the horizontal separation becomes zero.

Let the balls start at distances a and b from C along their slides. The initial horizontal separation is $(a + b) \cos \alpha$, and it vanishes when

$$\frac{1}{2}(2g \sin \alpha \cos \alpha) t^2 = (a + b) \cos \alpha \quad \Rightarrow \quad t^2 = \frac{a + b}{g \sin \alpha}.$$

But $a = \frac{1}{2}g \sin \alpha t_1^2$ and $b = \frac{1}{2}g \sin \alpha t_2^2$, so

$$t = \sqrt{\frac{t_1^2 + t_2^2}{2}}.$$

The smallest distance is the constant vertical separation,

$$d_{\min} = |a - b| \sin \alpha = \frac{1}{2} g \sin^2 \alpha |t_1^2 - t_2^2|.$$

$$\text{Answer: } t = \sqrt{(t_1^2 + t_2^2)/2}; d_{\min} = \frac{1}{2} g \sin^2 \alpha |t_1^2 - t_2^2|$$

Solution 1.6

At sea level the greatest range is obtained at 45° and $R = u^2/g$. At 45° the path is

$$y = x \tan 45^\circ - \frac{gx^2}{2u^2 \cos^2 45^\circ} = x - \frac{x^2}{R}.$$

From the cliff the shell lands where $y = -h$:

$$\frac{x^2}{R} - x - h = 0 \Rightarrow x = \frac{R}{2} \left(1 + \sqrt{1 + \frac{4h}{R}} \right).$$

With $h/R = 60/2000 = 0.03$: $\sqrt{1.12} = 1.0583$, so $x = 1.0292R = 2.058 \text{ km}$. The range increases by about 2.9%. (The elevation 45° is no longer the best one from the cliff; with a slightly smaller elevation the range would be a little larger still.)

$$\text{Answer: about 2.9 \% (range } \approx 2.06 \text{ km)}$$

Solution 1.7

Idea. The geometry fixes the motion of the centre; Newton's law then gives the forces. The supports are smooth, so the cylinder does not rotate and each normal force points along the radius to the contact point.

Put A at the origin and let $AB = d$. The centre is at $x = d/2$, $y = \sqrt{r^2 - d^2/4}$. With $\dot{d} = v$ (constant):

$$\dot{x} = \frac{v}{2}, \ddot{x} = 0; \quad y\dot{y} = -\frac{dv}{4} \Rightarrow \dot{y}^2 + y\ddot{y} = -\frac{v^2}{4}.$$

When $d = r\sqrt{2}$: $y = r/\sqrt{2}$ and $\dot{y} = -\frac{dv}{4y} = -\frac{v}{2}$. Hence

$$\ddot{y} = -\frac{v^2/4 + v^2/4}{r/\sqrt{2}} = -\frac{v^2}{\sqrt{2}r}.$$

Both radii to the supports now make 45° with the vertical. Since $\ddot{x} = 0$, the two normal forces are equal, $N_A = N_B = N$. Vertically,

$$2N \cos 45^\circ - mg = m\ddot{y} \Rightarrow N = \frac{mg}{\sqrt{2}} - \frac{mv^2}{2r}.$$

$$\text{Numerically } N = \frac{2 \times 10}{\sqrt{2}} - \frac{2 \times 1}{0.4} = 14.14 - 5.00 = 9.1 \text{ N}.$$

$$\text{Answer: } N = \frac{mg}{\sqrt{2}} - \frac{mv^2}{2r} \approx 9.1 \text{ N}$$

Solution 1.8

Idea. The bodies touch along a vertical face, so the force between them is horizontal and their horizontal velocities are always equal. Each moves along its own plane, and both planes make the same angle with the horizontal, so both have the same speed along the planes: the heavier one slides down while the lighter one is pushed up.

Let a be the common magnitude of acceleration along the planes (m_1 down, m_2 up) and N the horizontal contact force. Along the planes:

$$m_1 g \sin \alpha - N \cos \alpha = m_1 a, \quad N \cos \alpha - m_2 g \sin \alpha = m_2 a.$$

Adding, $a = \frac{(m_1 - m_2)g \sin \alpha}{m_1 + m_2}$; then

$$N = \frac{2m_1m_2g \tan \alpha}{m_1 + m_2} = \frac{2 \times 3 \times 1 \times 10 \times 0.75}{4} = 11.25 \text{ N}, \quad a = \frac{2 \times 10 \times 0.6}{4} = 3 \text{ m s}^{-2}.$$

Answer: $N = \frac{2m_1m_2g \tan \alpha}{m_1 + m_2} = 11.25 \text{ N}$; $a = 3 \text{ m s}^{-2}$ along each plane