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Momentum, Projectiles, Gravitation and Circular Motion

Name: ______________________________

Class: ______________________________

1. A fire hose on a rooftop in Tsim Sha Tsui directs a jet of water horizontally from a height of $20\ \mathrm{m}$ above street level with initial speed $12\ \mathrm{m\,s^{-1}}$. Neglect air resistance. Take $g = 9.81\ \mathrm{m\,s^{-2}}$. How far horizontally from the base of the building does the water hit the street?

A. $12\ \mathrm{m}$

B. $18\ \mathrm{m}$

C. $24\ \mathrm{m}$

D. $49\ \mathrm{m}$

2. Planet P has mass M and radius R. Planet Q has mass $2M$ and radius $2R$. The gravitational field strength on the surface of P is g_P. What is the gravitational field strength on the surface of Q?

A. $\frac{1}{4}g_P$

B. $\frac{1}{2}g_P$

C. g_P

D. $2g_P$

3. A satellite of mass m moves in a circular orbit of radius r about a planet of mass M. Which expression gives the orbital speed of the satellite?

A. $\sqrt{\frac{GM}{r}}$

B. $\sqrt{\frac{GMm}{r}}$

C. $\frac{GM}{r}$

D. $\sqrt{\frac{GM}{r^2}}$

4. An artificial satellite orbits the Earth in a circular path at a height equal to twice the Earth's radius above the surface. The acceleration due to gravity on the Earth's surface is g. What is the centripetal acceleration of the satellite?

A. $\frac{g}{9}$

B. $\frac{g}{4}$

C. $\frac{g}{3}$

D. $\frac{g}{2}$

5. On a smooth horizontal laboratory bench, cart A of mass $1.5\ \mathrm{kg}$ moves to the right at $4.0\ \mathrm{m\,s^{-1}}$ and collides head-on with cart B of mass $2.5\ \mathrm{kg}$, which is at rest. After the collision the two carts stick together. What is their common speed just after the collision?

A. $1.2\ \mathrm{m\,s^{-1}}$

B. $1.5\ \mathrm{m\,s^{-1}}$

C. $2.4\ \mathrm{m\,s^{-1}}$

D. $4.0\ \mathrm{m\,s^{-1}}$

6. A firework of mass $0.80\ \mathrm{kg}$ is moving horizontally at $25\ \mathrm{m\,s^{-1}}$ when it explodes into two fragments. Fragment X has mass $0.30\ \mathrm{kg}$ and moves horizontally forward at $40\ \mathrm{m\,s^{-1}}$ just after the explosion. What is the velocity of fragment Y just after the explosion? (Neglect external horizontal forces during the brief explosion.)

A. $16\ \mathrm{m\,s^{-1}}$ forward

B. $16\ \mathrm{m\,s^{-1}}$ backward

C. $9.0\ \mathrm{m\,s^{-1}}$ forward

D. $40\ \mathrm{m\,s^{-1}}$ forward

7. Sphere P of mass m moves to the right at speed u on a smooth horizontal surface and collides head-on with identical sphere Q which is at rest. After the collision P is at rest. Which statement is correct?

A. The collision must be perfectly inelastic.

B. Momentum is not conserved because P stops.

C. Q moves to the right at speed u and the collision is perfectly elastic.

D. Q moves to the right at speed $2u$.

8. A ball of mass $0.20\ \mathrm{kg}$ travelling horizontally at $15\ \mathrm{m\,s^{-1}}$ strikes a wall and rebounds along the same line at $9.0\ \mathrm{m\,s^{-1}}$. The ball is in contact with the wall for $0.040\ \mathrm{s}$. What is the magnitude of the average net force exerted on the ball by the wall? Neglect gravity during the impact.

A. $30\ \mathrm{N}$

B. $60\ \mathrm{N}$

C. $120\ \mathrm{N}$

D. $240\ \mathrm{N}$

9. A small mass is tied to a light string and whirled in a horizontal circle of radius $0.50\ \mathrm{m}$ on a smooth table. The mass completes 2.0 revolutions every second. What is the magnitude of its centripetal acceleration?

A. $20\ \mathrm{m\,s^{-2}}$

B. $40\ \mathrm{m\,s^{-2}}$

C. $79\ \mathrm{m\,s^{-2}}$

D. $158\ \mathrm{m\,s^{-2}}$

10. A car of mass m travels at constant speed on a level circular track of radius r. The total frictional force that provides the centripetal force has magnitude f. Which statement is correct?

A. The net force on the car is zero because speed is constant.

B. The centripetal force is $f = \dfrac{mv^2}{r}$ and is directed toward the centre of the circle.

C. The centripetal force is provided by the car’s weight.

D. Friction acts outward to balance an inward centrifugal force.

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Answers

1 C

Horizontal and vertical motions are independent.

Vertically the water starts from rest in the vertical direction:

$$h = \frac{1}{2}gt^2$$

$$20 = \frac{1}{2}(9.81)t^2$$

$$t^2 = \frac{40}{9.81} \approx 4.077$$

$$t \approx 2.02\ \mathrm{s}$$

Horizontally, speed is constant:
$R = u_x t = 12 \times 2.02 \approx 24.2\ \mathrm{m}.$

So the water lands about $24\ \mathrm{m}$ from the base.

2 B

Gravitational field strength at the surface is $g = \dfrac{GM}{r^2}$.

For P: $g_P = \dfrac{GM}{R^2}$.

For Q: $g_Q = \dfrac{G(2M)}{(2R)^2} = \dfrac{2GM}{4R^2} = \dfrac{1}{2}\dfrac{GM}{R^2} = \dfrac{1}{2}g_P.$

Therefore the surface field on Q is $\dfrac{1}{2}g_P$.

3 A

The gravitational force provides the centripetal force:
$\frac{GMm}{r^2} = \frac{mv^2}{r}$.

Cancel m and rearrange:
$v^2 = \frac{GM}{r}$
$v = \sqrt{\frac{GM}{r}}$.

The orbital speed depends on M and r, not on the satellite mass m.

4 A

Orbital radius from Earth's centre: $r = R + 2R = 3R$, where R is Earth's radius.

Surface field: $g = \frac{GM}{R^2}$, so $GM = gR^2$.

Acceleration at distance r:
$a = \frac{GM}{r^2} = \frac{gR^2}{(3R)^2} = \frac{gR^2}{9R^2} = \frac{g}{9}$.

Hence the satellite's centripetal acceleration is $g/9$.

5 B

Momentum is conserved in the absence of external horizontal forces.

Take right as positive.
Total momentum before: $1.5 \times 4.0 + 2.5 \times 0 = 6.0\,\mathrm{kg\,m\,s^{-1}}$.

After they stick, total mass $= 4.0\,\mathrm{kg}$:
$4.0\,v = 6.0$
$v = 1.5\,\mathrm{m\,s^{-1}}$ to the right.

The collision is perfectly inelastic; kinetic energy is not conserved, but momentum is.

6 A

Horizontal momentum is conserved.

Before: $p = 0.80 \times 25 = 20\ \mathrm{kg\,m\,s^{-1}}$ (forward positive).

After: $0.30 \times 40 + 0.50\, v_Y = 20$
$12 + 0.50 v_Y = 20$
$0.50 v_Y = 8$
$v_Y = 16\ \mathrm{m\,s^{-1}}$ forward.

So fragment Y continues forward at $16\ \mathrm{m\,s^{-1}}$.

7 C

Conservation of momentum:
$mu + 0 = m(0) + mv_Q \Rightarrow v_Q = u.$

Kinetic energy before: $\frac{1}{2}mu^2$.

Kinetic energy after: $\frac{1}{2}mu^2$.

KE is conserved, so the collision is perfectly elastic, and Q moves off at speed u while P stops. This is the classic equal-mass elastic result.

8 C

Net force equals the rate of change of momentum: $F = \dfrac{\Delta p}{\Delta t}$.

Take the initial direction as positive: $u = +15\ \mathrm{m\,s^{-1}}$, $v = -9.0\ \mathrm{m\,s^{-1}}$.

$\Delta p = m(v - u) = 0.20(-9.0 - 15) = 0.20 \times (-24) = -4.8\ \mathrm{kg\,m\,s^{-1}}$.

$$|F| = \frac{4.8}{0.040} = 120\ \mathrm{N}.$$

The wall exerts an average force of magnitude $120\ \mathrm{N}$ on the ball.

9 C

Frequency $f = 2.0 \text{ Hz}$, so angular speed $\omega = 2\pi f = 4\pi \text{ rad s}^{-1}$.

Linear speed $v = \omega r = 4\pi \times 0.50 = 2\pi \text{ m s}^{-1}$.

Centripetal acceleration:
$a = \frac{v^2}{r} = \frac{(2\pi)^2}{0.50} = \frac{4\pi^2}{0.50} = 8\pi^2 \approx 79 \text{ m s}^{-2}$.

Alternatively, $a = \omega^2 r = (4\pi)^2(0.50) = 8\pi^2$ same result.

Closest option: 79 m s^{-2}.

10 B

For uniform circular motion the net force toward the centre is the centripetal force:
$F_c = \frac{mv^2}{r} = f$.

Friction toward the centre is therefore equal to $\frac{mv^2}{r}$. The car's speed is constant in magnitude, so there is no tangential acceleration; the net force is purely radial (centripetal). Weight and normal reaction cancel vertically.