4.17 9.9 m s^{-2}, along the radius at every point towards the centre.

4.18 6.4 g

4.19 (a) False (true only for uniform circular motion)

(b) True, (c) True.

4.20 (a) $\mathbf{v}(t) = (3.0\ \hat{\mathbf{i}} - 4.0t\ \hat{\mathbf{j}})\ \ \hat{\mathbf{a}}(t) = -4.0\hat{\mathbf{j}}$

(b) 8.54 m s^{-1}, 70° with *x*-axis.

4.21 (a) 2 s, 24 m, 21.26 m s^{-1}

4.22 $\sqrt{2}$, 45° with the *x*-axis; $\sqrt{2}$, – 45° with the *x* - axis, $\left(5/\sqrt{2},\ -1/\sqrt{2}\right)$.

4.23 (b) and (e)

4.24 Only (e) is true

4.25 182 m s^{-1}

4.27 No. Rotations in *general* cannot be associated with vectors

4.28 A vector can be associated with a plane area

4.29 No

4.30 At an angle of $\sin^{-1}$ (1/3) = 19.5° with the vertical; 16 km.

4.31 0.86 m s^{-2}, 54.5° with the direction of velocity

Chapter 5

5.1 (a) to (d) No net force according to the First Law
(e) No force, since it is far away from all material agencies producing electromagnetic and gravitational forces.

5.2 The only force in each case is the force of gravity, (neglecting effects of air) equal to 0.5 N vertically downward. The answers do not change, even if the motion of the pebble is not along the vertical. The pebble is not at rest at the highest point. It has a constant horizontal component of velocity throughout its motion.

5.3 (a) 1 N vertically downwards (b) same as in (a)
(c) same as in (a); force at an instant depends on the situation at that instant, not on history.
(d) 0.1 N in the direction of motion of the train.

5.4 (i) T

5.5 $a = -2.5$ m s^{-2}. Using $v = u + at$, $0 = 15 - 2.5\,t$ i.e., $t = 6.0$ s

5.6 $a = 1.5/25 = 0.06$ m s^{-2}
$F = 3 \times 0.06 = 0.18$ N in the direction of motion.

5.7 Resultant force = 10 N at an angle of $\tan^{-1}$ (3/4) = 37° with the direction of 8 N force. Acceleration = 2 m s^{-2} in the direction of the resultant force.

5.8 $a = -2.5$ m s^{-2} , Retarding force = 465 × 2.5 = 1.2 × 10^3 N

5.9 $F - 20{,}000 \times 10 = 20000 \times 5.0$, i.e., $F = 3.0 \times 10^5$ N

5.10 $a = -20$ m s^{-2} $0 \le t \le 30$ s

$t = -5$ s : $x = u\,t = -\,10 \times 5 = -50$ m

$t = 25$ s : $x = u\,t + (½)\ a\,t^2 = (10 \times 25 - 10 \times 625)$m $= -\,6$ km

$t = 100$ s : First consider motion up to 30 s

$x_1 = 10 \times 30 - 10 \times 900 = -\,8700$ m

At $t = 30$ s, $v = 10 - 20 \times 30 = -590$ m s^{-1}

For motion from 30 s to 100 s : $x_2 = -\,590 \times 70 = -\,41300$ m

$x = x_1 + x_2 = -\,50$ km

5.11 (a) Velocity of car (at $t = 10$ s) = $0 + 2 \times 10 = 20$ m s^{-1}

By the First Law, the horizontal component of velocity is 20 m s^{-1} throughout.
Vertical component of velocity (at $t = 11$s) = $0 + 10 \times 1 = 10$ m s^{-1}

Velocity of stone (at $t = 11$s) $= \sqrt{20^2 + 10^2} = \sqrt{500} = 22.4$ m s^{-1} at an angle of $\tan^{-1}$ (½) with the horizontal.
(b) 10 m s^{-2} vertically downwards.

5.12 (a) At the extreme position, the speed of the bob is zero. If the string is cut, it will fall vertically downwards.
(b) At the mean position, the bob has a horizontal velocity. If the string is cut, it will fall along a parabolic path.

5.13 The reading on the scale is a measure of the force on the floor by the man. By the Third Law, this is equal and opposite to the normal force N on the man by the floor.

(a) $N = 70 \times 10 = 700$ N ; Reading is 70 kg
(b) $70 \times 10 - N = 70 \times 5$; Reading is 35 kg
(c) $N - 70 \times 10 = 70 \times 5$; Reading is 105 kg
(d) $70 \times 10 - N = 70 \times 10$; Reading would be zero; the scale would read zero.

5.14 (a) In all the three intervals, acceleration and, therefore, force are zero.
(b) 3 kg m s^{-1} at $t = 0$; (c) –3 kg m s^{-1} at $t = 4$ s.

5.15 If the 20 kg mass is pulled,
$600 - T = 20\,a$, $T = 10\,a$
$a = 20$ m s^{-2}, $T = 200$ N
If the 10 kg mass is pulled, a = 20 m s^{-2}, $T = 400$ N

5.16 $T - 8 \times 10 = 8\,a$, $12 \times 10 - T = 12a$
i.e. $a = 2$ m s^{-2}, $T = 96$ N

5.17 By momentum conservation principle, total final momentum is zero. Two momentum vectors cannot sum to a null momentum unless they are equal and opposite.

5.18 Impulse on each ball = $0.05 \times 12 = 0.6$ kg m s^{-1} in magnitude. The two impulses are opposite in direction.

5.19 Use momentum conservation : $100\,v = 0.02 \times 80$
$v = 0.016$ m s^{-1} = 1.6 cm s^{-1}

5.20 Impulse is directed along the bisector of the initial and final directions. Its magnitude is $0.15 \times 2 \times 15 \times \cos 22.5° = 4.2$ kg m s^{-1}

5.21 $$v = 2\pi \times 1.5 \times \frac{40}{60} = 2\pi \,\text{m s}^{-1}$$

$$T = \frac{mv^2}{R} = \frac{0.25 \times 4\pi^2}{1.5} = 6.6\,\text{N}$$

$200 = \frac{mv_{max}^2}{R}$, which gives $v_{max} = 35\ \text{m s}^{-1}$

5.22 Alternative (b) is correct, according to the First Law

5.23 (a) The horse-cart system has no external force in empty space. The mutual forces between the horse and the cart cancel (Third Law). On the ground, the contact force between the system and the ground (friction) causes their motion from rest.

(b) Due to inertia of the body not directly in contact with the seat.
(c) A lawn mower is pulled or pushed by applying force at an angle. When you push, the normal force (N) must be more than its weight, for equilibrium in the vertical direction. This results in greater friction f ($f \propto N$) and, therefore, a greater applied force to move. Just the opposite happens while pulling.

(d) To reduce the rate of change of momentum and hence to reduce the force necessary to stop the ball.

5.24 A body with a constant speed of 1 cm s^{-1} receives impulse of magnitude 0.04 kg × 0.02 m s^{-1} = 8×10^{-4} kg m s^{-1} after every 2 s from the walls at $x = 0$ and $x = 2$ cm.

5.25 Net force = 65 kg × 1 m s^{-2} = 65 N

$a_{max} = \mu_s g = 2\ \text{m s}^{-2}$

5.26 Alternative (a) is correct. Note $mg + T_2 = m\boldsymbol{v}_2^2/R$; $T_1 - mg = m\boldsymbol{v}_1^2/R$

The moral is : do not confuse the actual material forces on a body (tension, gravitational force, etc) with the effects they produce : centripetal acceleration $\boldsymbol{v}_2^2/R$ or $\boldsymbol{v}_1^2/R$ in this example.

5.27 (a) 'Free body' : crew and passengers

Force on the system by the floor = F upwards; weight of system = mg downwards;

$\therefore F - mg = ma$

$F - 300 \times 10 = 300 \times 15$

$F = 7.5 \times 10^3$ N upward

By the Third Law, force on the floor by the crew and passengers = 7.5×10^3 N downwards.

(b) 'Free body' : helicopter plus the crew and passengers

Force by air on the system = R upwards; weight of system = mg downwards

$\therefore R - mg = ma$

$R - 1300 \times 10 = 1300 \times 15$

$R = 3.25 \times 10^4$ N upwards

By the Third Law, force (action) on the air by the helicopter = 3.25×10^4 N downwards.

(c) 3.25×10^4 N upwards

5.28 Mass of water hitting the wall per second

$= 10^3\ \text{kg m}^{-3} \times 10^{-2}\ \text{m}^2 \times 15\ \text{m s}^{-1} = 150\ \text{kg s}^{-1}$

Force by the wall = momentum loss of water per second = 150 kg s^{-1} × 15 m s^{-1} = 2.25×10^3 N

5.29 (a) 3 mg (down) (b) 3 mg (down) (c) 4 mg (up)

5.30 If N is the normal force on the wings,

$$N\cos\theta = mg, \qquad N\sin\theta = \frac{mv^2}{R}$$

which give $R = \dfrac{v^2}{g\ \tan\ \theta} = \dfrac{200\times200}{10\times\tan15°} = 15\text{km}$

5.31 The centripetal force is provided by the lateral thrust by the rail on the flanges of the wheels. By the Third Law, the train exerts an equal and opposite thrust on the rail causing its wear and tear.

Angle of banking = $\tan^{-1}\left(\dfrac{v^2}{R\,g}\right) = \tan^{-1}\left(\dfrac{15\times15}{30\times10}\right) \simeq 37°$

5.32 Consider the forces on the man in equilibrium : his weight, force due to the rope and normal force due to the floor.

(a) 750 N (b) 250 N; mode (b) should be adopted.

5.33 (a) $T - 400 = 240$, $T = 640$ N

(b) $400 - T = 160$, $T = 240$ N

(c) $T = 400$ N

(d) $T = 0$

The rope will break in case (a).

5.34 We assume perfect contact between bodies A and B and the rigid partition. In that case, the self-adjusting normal force on B by the partition (reaction) equals 200 N. There is no impending motion and no friction. The action-reaction forces between A and B are also 200 N. When the partition is removed, kinetic friction comes into play.

Acceleration of A + B = [200 – (150 × 0.15)] / 15 =11.8 m s^{-2}

Friction on A = 0.15 × 50 = 7.5 N

200 – 7.5 – F_{AB} = 5 × 11.8

$F_{AB} = 1.3 \times 10^2$ N; opposite to motion .

$F_{BA} = 1.3 \times 10^2$ N; in the direction of motion.

5.35 (a) Maximum frictional force possible for opposing impending relative motion between the block and the trolley = 150 × 0.18 = 27 N, which is more than the frictional force of 15 × 0.5 = 7.5 N needed to accelerate the box with the trolley. When the trolley moves with uniform velocity, there is no force of friction acting on the block.

(b) For the accelerated (non-inertial) observer, frictional force is opposed by the pseudo-force of the same magnitude, keeping the box at rest relative to the observer. When the trolley moves with uniform velocity there is no pseudo-force for the moving (inertial) observer and no friction.

5.36 Acceleration of the box due to friction = $\mu g = 0.15 \times 10 = 1.5$ m s^{-2}. But the acceleration of the truck is greater. The acceleration of the box relative to the truck is 0.5 m s^{-2} towards the rear end. The time taken for the box to fall off the truck = $\sqrt{\dfrac{2\times5}{0.5}} = \sqrt{20}$ s.

During this time, the truck covers a distance = ½ × 2 × 20 = 20 m.

5.37 For the coin to revolve with the disc, the force of friction should be enough to provide the necessary centripetal force, i.e $\frac{mv^2}{r} \le \mu m g$. Now $v = r\omega$, where $\omega = \frac{2\pi}{T}$ is the angular frequency of the disc. For a given μ and ω, the condition is $r \le \mu g / \omega^2$. The condition is satisfied by the nearer coin (4 cm from the centre).

5.38 At the uppermost point, $N + mg = \frac{mv^2}{R}$, where N is the normal force (downwards) on the motorcyclist by the ceiling of the chamber. The minimum possible speed at the uppermost point corresponds to $N = 0$.

i.e. $v_{min} = \sqrt{Rg} = \sqrt{25 \times 10} = 16 \text{ m s}^{-1}$

5.39 The horizontal force N by the wall on the man provides the needed centripetal force : $N = m R \omega^2$. The frictional force f (vertically upwards) opposes the weight mg. The man remains stuck to the wall after the floor is removed if $mg = f < \mu N$ i.e. $mg < \mu m R \omega^2$. The minimum angular speed of rotation of the cylinder is $\omega_{min} = \sqrt{g / \mu R} = 5 \text{ s}^{-1}$

5.40 Consider the free-body diagram of the bead when the radius vector joining the centre of the wire makes an angle θ with the vertical downward direction. We have $mg = N\cos\theta$ and $m R \sin\theta \, \omega^2 = N \sin\theta$. These equations give $\cos\theta = g/R\omega^2$. Since $\cos\theta \le 1$, the bead remains at its lowermost point for $\omega \le \sqrt{\frac{g}{R}}$.

For $\omega = \sqrt{\frac{2g}{R}}$, $\cos\theta = \frac{1}{2}$ i.e. $\theta = 60^0$.

Chapter 6

6.1 (a) +ve (b) –ve (c) –ve (d) + ve (e) – ve

6.2 (a) 882 J ; (b) –247 J; (c) 635 J ; (d) 635 J;
Work done by the net force on a body equals change in its kinetic energy.

6.3 (a) $x > a$; 0 (c) $x < a$, $x > b$; $-V_1$
(b) $-\infty < x < \infty$; V_1 (d) $-b/2 < x < -a/2$, $a/2 < x < b/2$; $-V_1$

6.5 (a) rocket; (b) For a conservative force work done over a path is minus of change in potential energy. Over a complete orbit, there is no change in potential energy; (c) K.E. increases, but P.E. decreases, and the sum decreases due to dissipation against friction; (d) in the second case.

6.6 (a) decrease; (b) kinetic energy; (c) external force; (d) total linear momentum, and also total energy (if the system of two bodies is isolated).

6.7 (a) F ; (b) F ; (c) F ; (d) F (true usually but not always, why?)

6.8 (a) No
(b) Yes
(c) Linear momentum is conserved during an inelastic collision, kinetic energy is, of course, not conserved even after the collision is over.
(d) elastic.

6.9 (b) t