Exercise

A — Multiple Choice Questions (answer + explanation)

3.1. (d) reaction.
When you kick a stone the stone exerts an equal and opposite force on your foot (Newton's third law). That reaction force (and the sudden change in momentum of your foot) causes pain.

3.2. (a) the resultant force on it begins to decrease.
An object has constant acceleration so long as the resultant (net) force on it remains constant. If the resultant force begins to change (for example begins to decrease — option (a) — or begins to increase), the acceleration will change. The intended textbook choice is (a) because the moment the resultant force changes (starts to decrease) the acceleration ceases to be the previous constant value.

3.3. (c) Electrostatic force.
Electrostatic (Coulomb) force acts at a distance (non-contact). Friction, air resistance and tension are contact forces.

3.4. (b) $p_{\text{after}} = -p$**.**
If the ball bounces back with the same speed but reversed direction, its momentum reverses sign (same magnitude, opposite direction).

3.5. (c) 0.
For a head-on elastic collision between two equal masses where the second is initially at rest, the first comes to rest and the second takes the first's velocity. So the velocity of the first after collision is zero.

3.6. (c) Newton's third law of motion.
Conservation of linear momentum for interacting bodies follows from Newton's third law: action and reaction forces between particles are equal and opposite, so internal forces cancel and total momentum of an isolated system is constant.

3.7. (c) -12 N.
Using impulse/momentum: $F\Delta t = m(v-u)$. Here $m = 5$ kg, $u = +10$ m/s, $v = -2$ m/s, $\Delta t = 5$ s. So $F = 5(-2-10)/5 = -12$ N. Negative sign means the force is opposite to the original direction of motion.

3.8. (c) product of force and time (the impulse).
For a very large force acting over a very short time it is usually impractical to measure the instantaneous force or exact time; the easily measurable quantity is the impulse $J = F\Delta t$, which equals the change of momentum.

3.9. (c) prevents direct contact of the surfaces.
A lubricant forms a thin film between surfaces, preventing direct asperity contact and thus reducing friction and wear.

B — Short Answer Questions (comprehensive)

3.1. What kind of changes in motion may be produced by a force?
A force can change an object's motion by: (i) changing its **speed** (speeding up or slowing down), (ii) changing its **direction** (turning it), or (iii) changing both speed and direction simultaneously. All such changes are described by acceleration (vector rate of change of velocity).

3.2. Give 5 examples of contact forces.

1. Frictional force (between sliding surfaces)
2. Normal (support) force from a surface
3. Tension in a string or rope
4. Applied push or pull (e.g., you push a book)
5. Air resistance (drag) when an object moves through air
   (Each acts through direct contact of surfaces or medium.)

3.3. An object moves with constant velocity in free space. How long will the object continue to move with this velocity?
Indefinitely — it will continue forever with that constant velocity **until** an external resultant force acts on it (Newton's first law). In free space, absent forces, no change occurs.

3.4. Define impulse of force.
Impulse J is the product of average force and the time interval over which it acts: $J = F\Delta t$. It equals the change in linear momentum: $J = \Delta p = m(v_f - v_i)$. Unit: newton-second (N·s).

3.5. Why has not Newton's first law been proved on the Earth?
Because on Earth we cannot completely remove external forces such as friction and air resistance. Newton's first law refers to motion in the absence of any net external force; in practice we can only approximate that condition (e.g., near-frictionless surfaces or space). Thus the law is a principle/postulate validated by observations when external forces are negligible, not a directly provable theorem on Earth where residual forces exist.

3.6. When sitting in a car which suddenly accelerates from rest, you are pushed back into the seat — why?
Your body has inertia (tendency to remain at rest). When the car is accelerated forward, the seat moves forward under you; relative to the car you appear to be pushed backward into the seat because your body tends to keep its original state. The seat supplies a backward reaction on your body (contact force) so you accelerate with the car.

3.7. The force expressed in Newton's second law is a net force. Why is it so?
Newton's second law $\vec{F}_{\text{net}} = m\vec{a}$ uses the vector sum of all forces on the object because individual forces combine to produce the total (resultant) effect that gives acceleration. Only the resultant (net) force determines the acceleration; opposing forces partially cancel and only the net remains to produce motion change.

3.8. How can you show that rolling friction is lesser than sliding friction?
Perform a simple experiment: pull a wheel-bearing-loaded object (roll) and measure the force required; then force the same object to slide and measure the force. Typically the pull-force for rolling is much smaller. Explanation: rolling friction arises mainly from small deformations at the contact area; sliding friction involves continual breaking and reforming of microscopic contacts, which dissipates more energy, so kinetic (sliding) friction f_k is usually larger than rolling friction.

3.9. Define terminal velocity of an object.
Terminal velocity is the constant speed an object reaches when the downward force of gravity equals the upward resistive force (drag) so net force = 0 and acceleration = 0. For high-speed drag proportional to v^2, terminal speed satisfies $mg = kv_{\text{term}}^2$, hence $v_{\text{term}} = \sqrt{mg/k}$ (depends on mass, shape, and fluid).

3.10. An astronaut walking in space wants to return to his spaceship by firing a hand rocket. In what direction does he fire the rocket?
He fires the rocket **away from the spaceship**. By ejecting mass (gas) in the direction away from the ship, the reaction force pushes the astronaut toward the ship (conservation of momentum).

C — Constructed Response Questions (detailed)

3.1. Two ice skaters (60 kg and 80 kg) push off on frictionless ice. The 60 kg skater gains 4 m/s**. Explain Newton's third law and compute the 80 kg skater's velocity.**

- Conservation of momentum (system initially at rest): $m_1v_1 + m_2v_2 = 0$.
  With $m_1 = 60$ kg, $v_1 = +4$ m/s, solve for v_2:
  $$v_2 = -\frac{m_1v_1}{m_2} = -\frac{60 \times 4}{80} = -3 \text{ m/s}.$$
  So the 80 kg skater moves at 3 m/s in the opposite direction.

- Newton's third law: when they push each other, each skater exerts an equal and opposite force on the other. The impulses (force × time) are equal and opposite, producing equal-magnitude momenta in opposite directions: $|p_1| = |p_2| = 60 \times 4 = 240$ kg·m/s.

3.2. Airbags vs seatbelts (momentum argument).
Airbags increase the time interval over which the passenger's momentum changes during a crash. From $F_{\text{avg}} = \Delta p/\Delta t$: for the same change of momentum Δp, a larger Δt (airbag cushioning) means a smaller average force on the body. Airbags also spread the force over a larger area and reduce head/face impact velocity. Seatbelts restrain motion and prevent ejection but combined with airbags they reduce peak forces most effectively.

3.3. Horse–cart argument (what is wrong).
The horse's reasoning misapplies Newton's third law: action–reaction forces act on **different** bodies (horse and cart), so they do **not** cancel on a single body. To move the cart forward, the horse pushes backward on the ground; the ground pushes forward on the horse (friction). The forward frictional force on the horse accelerates the horse and via the harness

transmits forward force to the cart. Thus net forward force on the horse–cart system is not necessarily zero (because the ground supplies external force) and motion can occur.

3.4. Why a fielder draws hands backward when catching a high ball.
Drawing hands backward increases the time of impact Δt, so by $F_{\text{avg}} = \Delta p/\Delta t$ the average force on the hand (and ball) is reduced. This reduces injury and prevents the ball from rebounding out.

3.5. Why jumper often falls into the water when jumping from small boat to bank.
When the jumper pushes off the boat toward the bank, by action there is reaction on the boat in the opposite direction — the boat moves back. If the boat recoils enough, relative positions change and the jumper may miss the bank and fall into water. The boat–jumper interaction and finite friction with water/ground lead to this effect.

3.6. If friction vanished suddenly — real-life consequences.
Many everyday actions would fail: walking/running (no traction), driving (tires cannot grip road), writing (pen slips), holding objects (they slide out of hands), stopping vehicles impossible (no braking), matches cannot be struck, and liquids and objects would not rest on inclined surfaces. Transport, manufacturing, and biological activities rely heavily on friction, so life would be drastically altered.

D — Comprehensive Questions (concise but thorough answers)

3.1. Explain the concept of force by practical examples.
A **force** is a push or pull that can change an object's state of motion or shape. It is a vector (has magnitude and direction). SI unit: newton (N), where $1\text{ N} = 1\text{ kg·m/s}^2$. Examples: gravity pulling an apple downward, a person pushing a shopping cart, tension pulling a suspended lamp upward, friction resisting sliding, and air resistance slowing a falling feather. Forces are represented on free-body diagrams as arrows applied at the point of contact or application.

3.2. Describe Newton's laws of motion.

- **First law (Inertia):** A body remains at rest or moves with constant velocity unless acted on by a net external force.
- **Second law:** $\vec{F}_{\text{net}} = m\vec{a}$; equivalently $\vec{F}_{\text{net}} = \frac{d\vec{p}}{dt}$. It quantifies how net force changes motion.
- **Third law:** For every action there is an equal and opposite reaction: forces between two bodies are equal in magnitude and opposite in direction and act on different bodies.

3.3. Define momentum and Newton's 2nd law in momentum form.
Linear momentum $\vec{p} = m\vec{v}$. Newton's second law in momentum form: $\vec{F}_{\text{net}} = \frac{d\vec{p}}{dt}$. For constant mass, this reduces to $m\frac{d\vec{v}}{dt} = m\vec{a}$. For variable-mass systems (rockets) the full momentum form must be used.

3.4. State and explain conservation of momentum.
Total linear momentum of an isolated system (no external resultant force) remains constant in time. Derivation: by Newton's third law internal forces cancel pairwise, so $d\vec{p}_{\text{total}}/dt = \vec{F}_{\text{external}} = 0$. Application: collisions — total momentum before = total momentum after.

3.5. Motion of a block on table with friction; static vs kinetic friction.

- If applied horizontal force F is small, static friction f_s balances it up to a maximum $f_{s,\max} = \mu_s N$ (no motion). When $F > f_{s,\max}$ the block begins to slide and kinetic (sliding) friction $f_k = \mu_k N$ opposes motion. Typically $\mu_s > \mu_k$. Net horizontal acceleration when sliding: $a = (F - f_k)/m$. Normal $N = mg$ (horizontal table surface), so $f_k = \mu_k mg$. Static friction is self-adjusting up to its maximum; kinetic friction is (approximately) roughly constant while sliding.

3.6. Effect of friction on vehicle motion — tyres & braking.
Tyre–road friction (traction) determines acceleration, braking force and cornering ability. Higher coefficient of friction gives shorter stopping distance and better acceleration. Wet/icy surfaces reduce μ, increasing stopping distance. Braking relies on static friction (tyre contact) — if wheels lock and slide, kinetic friction is lower, stopping distance grows and steering is lost. Modern systems (ABS) prevent wheel lock, keeping tyres in static friction regime to maximize control. Brake design, tyre tread, temperature and road texture are important.

E — Numerical Problems (step-by-step)

3.1. *A 10 kg block on a smooth horizontal surface. A horizontal force 5 N is applied.*
(a) Acceleration: $a = \frac{F}{m} = \frac{5}{10} = 0.5\ \text{m/s}^2$.
(b) Velocity after 5 s (from rest): $v = u + at = 0 + 0.5 \times 5 = 2.5$ m/s.

3.2. *Mass of person = 80 kg. Weight on Earth and on Moon (Moon $g = 1.6\ \text{m/s}^2$).*

- Using Using gEarth=10 m/s^2 , WEarth=80×10=800 N
- Using Approximate: Using gEarth=9.8 m/s^2 , WEarth=80×9.8=784 N
- On the Moon: WMoon=80×1.6=128 N.
- (Students: many textbooks use $g = 10$ so 800 N is the "textbook" answer; 784 N is the value with $g = 9.8$.)

3.3. *Force to increase velocity of 800 kg car from 10 to 30 m/s in 10 s.*
$\Delta v = 20$ m/s. $a = \Delta v/\Delta t = 20/10 = 2\ \text{m/s}^2$.

$$F = ma = 800 \times 2 = 1600\ \text{N}.$$

3.4. *5 g bullet (0.005 kg) at 300 m/s; gun mass 10 kg. Recoil speed of gun.*
Conserve momentum: $m_b v_b + m_g v_g = 0 \Rightarrow v_g = -\frac{m_b v_b}{m_g} = -\frac{0.005 \times 300}{10} = -0.15$ m/s.

(Negative sign = opposite direction to bullet.)

3.5. *Astronaut 70 kg throws wrench 300 g (0.3 kg) at 3.5 m/s.*
(a) Speed of astronaut: $v_{\text{ast}} = -\frac{m_{\text{wrench}} v_{\text{wrench}}}{m_{\text{ast}}} = -\frac{0.3 \times 3.5}{70} = -0.015$ m/s.
(That is 1.5×10^{-2} m/s away from the throw direction.)
(b) Distance in 30 minutes (1800 s): $d = |v_{\text{ast}}| \times 1800 = 0.015 \times 1800 = 27$ m.

3.6. *Two bogies* $m_1 = 6.5 \times 10^4$ kg *at 0.8 m/s and* $m_2 = 9.2 \times 10^4$ kg *at 1.2 m/s; they collide and couple. Common velocity?*
Conserve momentum: $v_{\text{common}} = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2} = \frac{65000 \times 0.8 + 92000 \times 1.2}{65000 + 92000}$.
Numerically $v_{\text{common}} \approx 1.03$ m/s.

3.7. *Cyclist (55 kg) + bicycle (5 kg) = total 60 kg. Force 90 N for 8 s, then constant speed for 8 s.*

- Acceleration during first 8 s: $a = F/m = 90/60 = 1.5$ m/s^2.
- Distance while accelerating: $s_1 = 1/2\, at^2 = 0.5 \times 1.5 \times 8^2 = 48$ m.
- Velocity after 8 s: $v = at = 1.5 \times 8 = 12$ m/s.
- Distance at constant speed for next 8 s: $s_2 = v \times 8 = 12 \times 8 = 96$ m.
- Total distance $= 48 + 96 = 144$ m.

3.8. *Ball (0.4 kg) dropped from 1.8 m, rebounds to 0.8 m. Find impulse magnitude and direction.*

- Speed just before impact $u = \sqrt{2gh_1}$. With $g = 9.8$, $u \approx 5.94$ m/s (downward).
- Speed just after rebound $v \approx \sqrt{2gh_2} \approx 3.96$ m/s (upward).
- Impulse (taking upward as positive): $J = m\big(v - (-u)\big) = m(u + v) = 0.4(5.9397 + 3.9598) \approx 3.96$ N·s upward.
  (Using $g = 10$ gives $u = \sqrt{2 \times 10 \times 1.8} = 6.0$ and $v = \sqrt{2 \times 10 \times 0.8} = 4.0$, so $J = 0.4(6 + 4) = 4.0$ N·s upward — that is the approximate textbook answer.)

3.9. *Two balls:* $m_1 = 0.2$ kg, $v_{1i} = +20$ m/s; $m_2 = 0.4$ kg, $v_{2i} = -5$ m/s. *After collision* $v_{1f} = 6$ m/s. *Find* v_{2f}.
Conserve momentum: $m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$. Solve:

$$v_{2f} = \frac{m_1\big(v_{1i} - v_{1f}\big) + m_2 v_{2i}}{m_2} = 2.0 \text{ m/s}$$