Unit 4 · Dynamics

ANSWER KEY · FOR TEACHERS

Full marks 32

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

1. inertia
2. momentum
3. impulse
4. newton
5. torque
6. couple
7. limiting friction
8. angle of repose

Each carries 0.5 mark. **K · 4**

2 Label the diagram

1. mg sin θ
2. R
3. mg cos θ
4. F

Each carries 0.5 mark. **K · 2**

3 Multiple choice

i. **a.** N s **K · 1**

Impulse = force × time, so newton second (the same as kg m/s, the unit of momentum).

ii. **b.** makes the stopping time longer, so the force is smaller **U · 1**

The change in momentum is fixed by the ball's speed. $F = \Delta p/\Delta t$: a longer Δt gives a smaller force on her hands.

iii. **b.** 2 m/s **A · 1**

Momentum before = 0, so $4V = 0.020 \times 400 = 8$, $V = 2$ m/s, backwards.

iv. **c.** 390 N **A · 1**

$R = m(g - a) = 50 \times (9.8 - 2) = 390$ N.

v. **a.** zero **U · 1**

Static friction adjusts itself to the force trying to move a body, up to the limiting value. With no push, there is nothing for it to oppose.

4 Short answers

a. **MARKING SCHEME** **U · 2**

- ✓ Action and reaction act on different bodies.
- ✓ Only forces on the same body can cancel (each body responds to the force on it).

b. **MARKING SCHEME** **U · 2**

- ✓ Torque τ = force × perpendicular distance from the axis (the hinges).
- ✓ A larger distance needs a smaller force for the same torque.

c. **MARKING SCHEME** **A · 3**

- ✓ Friction = $\mu_k mg = 117.6$ N.
- ✓ Steady speed means zero resultant force.
- ✓ Pull = friction ≈ 118 N.

Science Playground, Katunje, Bhaktapur
Book a class visit: https://science-playground.com/booking

5 Long answer

ANSWER U · 4

m_1 moves down and m_2 up, with the same acceleration a; the tension T is the same all along the string.
For m_1: $m_1g - T = m_1a$. For m_2: $T - m_2g = m_2a$.
Adding: $(m_1 - m_2)g = (m_1 + m_2)a$, so $a = \dfrac{(m_1 - m_2)g}{m_1 + m_2}$.
Then $T = m_2(g + a) = \dfrac{2m_1m_2g}{m_1 + m_2}$.
When $m_1 = m_2$, a = 0: the masses stay at rest (or move at a steady speed), and T = mg.

MARKING SCHEME

- ✓ The equation of motion for m_1: $m_1g - T = m_1a$.
- ✓ The equation for m_2: $T - m_2g = m_2a$.
- ✓ $a = (m_1 - m_2)g/(m_1 + m_2)$ and $T = 2m_1m_2g/(m_1 + m_2)$.
- ✓ For equal masses a = 0 (no acceleration) and T = mg.

6 Numerical problems

a. **ANSWER** A · 4

$v = \sqrt{(2gh)} = \sqrt{(2 \times 9.8 \times 1.0)} =$ **4.43 m/s**.
Her change in momentum is $45 \times 4.43 = 199$ kg m/s. While stopping, the ground's push R and her weight act: $(R - mg)\Delta t = \Delta p$, so $R = \Delta p/\Delta t + mg$.

i. $R = 199 \div 0.05 + 441 \approx$ **4430 N**, about ten times her weight.

ii. $R = 199 \div 0.40 + 441 \approx$ **940 N**, about twice her weight. Bending her knees makes the force almost five times smaller.

MARKING SCHEME

- ✓ v = 4.43 m/s.
- ✓ $\Delta p = 199$ kg m/s, and $R = \Delta p/\Delta t + mg$ (or the stopping force $\Delta p/\Delta t$).
- ✓ About 4430 N in 0.05 s (3980 N without the weight).
- ✓ About 940 N in 0.40 s (500 N without the weight).

b. **ANSWER** A · 3

By the principle of moments: $30g \times 2.0 = 40g \times d$, so $d = 60 \div 40 =$ **1.5 m** on the other side.
The pivot holds up both children (the plank's weight aside): $(30 + 40) \times 9.8 =$ **686 N**.

MARKING SCHEME

- ✓ Clockwise moment = anticlockwise moment: $30 \times 2.0 = 40 \times d$.
- ✓ d = 1.5 m.
- ✓ Pivot force 686 N (plus the plank's weight).

7 Think

ANSWER HA · 3

He throws the bag hard away from the edge he wants to reach. Before, he and the bag have zero total momentum, and no outside horizontal force acts, so the total stays zero: the bag's momentum one way is matched by his own the other way, mv = MV. He slides towards the edge, and keeps sliding, since there is no friction to stop him.

MARKING SCHEME

- ✓ Throw the bag away from the side he wants to reach.
- ✓ Conservation of momentum: total zero before and after, so he moves opposite to the bag (mv = MV).
- ✓ With no friction he keeps moving at a steady speed (first law).

Science Playground, Katunje, Bhaktapur
Book a class visit: https://science-playground.com/booking

8 Activity: The angle of repose

(not marked)

WHAT STUDENTS SHOULD FIND

Rubber grips best (the steepest angle, often μ above 0.5); a smooth coin slides at a small angle. The matchbox starts sliding at about the same angle on either side, so friction doesn't depend on the area of contact, one of the laws of friction. The angles vary a little from try to try: repeat and average.

See it at Science Playground

Exhibits and plants at the center, Bhaktapur, that go with this unit. Book a class visit at science-playground.com/booking.

- **Newton's Cradle** (exhibit): Release one ball, then two: the same number swing out at the far end, carrying on the momentum, while the middle balls barely move.
- **Saturn V - LEGO Model** (exhibit): The real Saturn V rose by throwing its exhaust gas down at high speed: the gas's downward momentum is matched by the rocket's upward momentum, gravity aside.
- **Walk Your Weight** (exhibit): Walk out from the pivot until the plank tips: it turns once your weight's moment, force × perpendicular distance, exceeds the moment on the other side.
- **Tensegrity — Floating in Balance** (exhibit): Nothing here moves: on every part the strings' pulls, the rods' pushes and the weight give zero resultant force and zero torque, equilibrium's two conditions.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	7	10	12	3	**32**