Year 11 Physics | Momentum and Energy

Teacher's fully worked solutions
Fundamentals of Mechanics — NESA Physics 11–12 Syllabus (2025)

Conventions: $g = 9.80\ \text{m s}^{-2}$. All numerical results use the values supplied in the worksheet; unrounded intermediate values are retained where needed. Directions and signs are made explicit. Work done by a force is signed, and kinetic energy is a scalar.

A | Foundations

Solution 1. Conservative and non-conservative forces

A conservative force does work that depends only on the initial and final positions (equivalently, its work around a closed path is zero). Gravity is conservative; kinetic friction is non-conservative. Total mechanical energy $K+U$ is constant when only conservative forces do work on the system, so no net energy is transferred out of mechanical forms by non-conservative work.

Solution 2. Kinetic energy

Use $K = \frac{1}{2}mv^2$.

$$K = \frac{1}{2}(1.50)(4.00)^2 = 12.0\ \text{J}.$$

When the speed doubles to $8.00\ \text{m s}^{-1}$,

$$K' = \frac{1}{2}(1.50)(8.00)^2 = 48.0\ \text{J}.$$

The kinetic energy becomes four times as large.

Solution 3. Gravitational potential energy

The increase in gravitational potential energy is

$$\Delta U = mg\Delta h = (3.00)(9.80)(2.50) = +73.5\ \text{J}.$$

Gravity acts downwards during an upward displacement, so

$$W_{\text{gravity}} = -mg\Delta h = -73.5\ \text{J}.$$

The lifting force does $+73.5$ J if the speed is constant.

Solution 4. Work done at an angle

The displacement is horizontal, so the angle between the applied force and displacement is 60.0°:

$$W = Fs\cos\theta = (40.0)(5.00)\cos 60.0^\circ = 100\ \text{J}.$$

The vertical force component does no work because there is no vertical displacement.

Solution 5. Momentum and impulse

Take east as positive. Momentum:

$$p = mv = (0.250)(+12.0) = +3.00 \text{ kg m s}^{-1}.$$

Since the ball stops,

$$\Delta p = p_f - p_i = 0 - 3.00 = -3.00 \text{ N s}.$$

Thus the impulse is 3.00 N s west. Average net force:

$$F_{\text{net,av}} = \frac{\Delta p}{\Delta t} = \frac{-3.00}{0.150} = -20.0 \text{ N}.$$

Answer: 20.0 N west.

B | Applying energy and momentum

Solution 6. The work–kinetic-energy theorem

The work done by the net force is

$$W_{\text{net}} = Fs = (15.0)(6.00) = 90.0 \text{ J}.$$

Apply the work–kinetic-energy theorem:

$$W_{\text{net}} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2.$$

$$90.0 = \frac{1}{2}(5.00)v_f^2 - \frac{1}{2}(5.00)(2.00)^2.$$

$$90.0 = 2.50v_f^2 - 10.0, \qquad v_f^2 = 40.0.$$

$$\boxed{v_f = 6.32 \text{ m s}^{-1}}.$$

Solution 7. Energy gained on a climb

The gravitational potential energy change is

$$\Delta U = mg\Delta h = (60.0)(9.80)(12.0) = 7.06 \times 10^3 \text{ J}.$$

At constant speed there is no change in kinetic energy. The increase in gravitational potential energy comes ultimately from chemical energy supplied by the cyclist, through work done against gravity (with additional energy required to overcome resistive forces in a real journey).

Solution 8. Vertical launch

(a) Initial kinetic energy:

$$K_i = \frac{1}{2}(0.400)(14.0)^2 = 39.2 \text{ J}.$$

(b) At maximum height $K_f = 0$. Therefore,

$$\frac{1}{2}mv_i^2 = mgh_{\text{max}}, \qquad h_{\text{max}} = \frac{(14.0)^2}{2(9.80)} = 10.0 \text{ m}.$$

(c) At $h = 6.00$ m,

$$\frac{1}{2}mv_i^2 = \frac{1}{2}mv^2 + mgh.$$

$$v^2 = (14.0)^2 - 2(9.80)(6.00) = 78.4.$$

$$\boxed{v = 8.85 \text{ m s}^{-1} \text{ upwards}}.$$

The rising branch fixes the direction; energy alone gives the speed.

Solution 9. Ramp with energy loss

Initial gravitational potential energy relative to the bottom is

$$U_i = mgh = (2.00)(9.80)(3.00) = 58.8 \text{ J}.$$

At the bottom,

$$K_f = \frac{1}{2}mv^2 = \frac{1}{2}(2.00)(6.00)^2 = 36.0 \text{ J}.$$

Thus the energy transformed out of mechanical forms is

$$E_{\text{transformed}} = 58.8 - 36.0 = \boxed{22.8 \text{ J}}.$$

This is not an isolated mechanical-energy-conserving descent.

Solution 10. Stopping a sliding object

The crate starts with

$$K_i = \frac{1}{2}mv_i^2 = \frac{1}{2}(4.00)(5.00)^2 = 50.0 \text{ J}.$$

The friction force does negative work $W_f = -10.0s$. Using $W_{\text{net}} = \Delta K$,

$$-10.0s = 0 - 50.0, \qquad \boxed{s = 5.00 \text{ m}}.$$

Weight and normal force perform zero work on the horizontal displacement.

Solution 11. Momentum versus kinetic energy

Trolley A:

$$p_A = (2.00)(3.00) = 6.00 \text{ kg m s}^{-1} \text{ east},$$

$$K_A = \frac{1}{2}(2.00)(3.00)^2 = 9.00 \text{ J}.$$

Trolley B:

$$p_B = (1.00)(6.00) = 6.00 \text{ kg m s}^{-1} \text{ east},$$

$$K_B = \frac{1}{2}(1.00)(6.00)^2 = 18.0 \text{ J}.$$

They have equal momentum but B has twice the kinetic energy. At fixed momentum magnitude, $K = p^2/(2m)$, so kinetic energy also depends on mass.

C | Collisions and impulse

Solution 12. Perfectly inelastic collision

Take right as positive. Momentum conservation gives

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v.$$

$$(0.600)(3.00) + (0.400)(0) = (1.00)v,$$

$$\boxed{v = +1.80\ \text{m s}^{-1}}.$$

Initial kinetic energy:

$$K_i = \frac{1}{2}(0.600)(3.00)^2 = 2.70\ \text{J}.$$

Final kinetic energy:

$$K_f = \frac{1}{2}(1.00)(1.80)^2 = 1.62\ \text{J}.$$

Mechanical energy transformed during impact:

$$K_i - K_f = 2.70 - 1.62 = \boxed{1.08\ \text{J}}.$$

Momentum is conserved, but kinetic energy is not.

Solution 13. Recoil

Take east as positive. Initially $p_{\text{total}} = 0$. With negligible external horizontal impulse,

$$0 = m_Av_A + m_Bv_B.$$

$$0 = (50.0)(+2.40) + (75.0)v_B,$$

$$v_B = -\frac{120}{75.0} = \boxed{-1.60\ \text{m s}^{-1}}.$$

Skater B travels **west at** $1.60\ \text{m s}^{-1}$. The skaters exert equal and opposite internal forces on one another, producing impulses that cancel in the total system momentum.

Solution 14. Identical trolleys: elastic collision

For an ideal elastic collision between equal masses in one dimension, the bodies exchange velocities:

$$v_1 = 0, \qquad v_2 = +2.00\ \text{m s}^{-1}.$$

Check momentum:

$$p_i = (0.500)(2.00) + (0.500)(0) = 1.00\ \text{kg m s}^{-1},$$

$$p_f = (0.500)(0) + (0.500)(2.00) = 1.00\ \text{kg m s}^{-1}.$$

Check kinetic energy:

$$K_i = \frac{1}{2}(0.500)(2.00)^2 = 1.00\ \text{J},$$

$$K_f = \frac{1}{2}(0.500)(2.00)^2 = 1.00\ \text{J}.$$

Both are conserved.

Solution 15. Unequal masses: elastic collision

Take right as positive. From momentum conservation,

$$2.00(3.00) + 1.00(0) = 2.00v_1 + 1.00v_2,$$
$$6.00 = 2.00v_1 + v_2. \tag{1}$$

For a one-dimensional elastic collision, the relative speed of separation equals the relative speed of approach:

$$v_2 - v_1 = u_1 - u_2 = 3.00. \tag{2}$$

From (2), $v_2 = v_1 + 3.00$. Substitute in (1):

$$6.00 = 2.00v_1 + (v_1 + 3.00),$$
$$v_1 = +1.00\ \text{m s}^{-1}, \qquad v_2 = +4.00\ \text{m s}^{-1}.$$

Both trolleys travel right. Check: $K_i = 9.00$ J and $K_f = \frac{1}{2}(2)(1)^2 + \frac{1}{2}(1)(4)^2 = 9.00$ J.

Solution 16. Classifying measured collisions

Take right as positive. In either set, initial momentum and kinetic energy are

$$p_i = (0.400)(3.00) = 1.20\ \text{kg m s}^{-1},$$
$$K_i = \frac{1}{2}(0.400)(3.00)^2 = 1.80\ \text{J}.$$

Set A:

$$p_f = (0.400)(1.00) + (0.200)(4.00) = 1.20\ \text{kg m s}^{-1},$$
$$K_f = \frac{1}{2}(0.400)(1.00)^2 + \frac{1}{2}(0.200)(4.00)^2 = 0.200 + 1.60 = 1.80\ \text{J}.$$

Momentum and kinetic energy are conserved: **elastic collision**.

Set B:

$$p_f = (0.400)(2.00) + (0.200)(2.00) = 1.20\ \text{kg m s}^{-1},$$
$$K_f = \frac{1}{2}(0.400)(2.00)^2 + \frac{1}{2}(0.200)(2.00)^2 = 0.800 + 0.400 = 1.20\ \text{J}.$$

Momentum is conserved, but kinetic energy decreases by 0.600 J: **inelastic collision** (perfectly inelastic if the two trolleys remain joined).

Solution 17. Ball rebounding from a floor

Take upwards as positive:

$$u = -12.0\ \text{m s}^{-1}, \quad v = +8.00\ \text{m s}^{-1}.$$

(a) Change in momentum:

$$\Delta p = m(v - u) = (0.150)[8.00 - (-12.0)] = \boxed{+3.00\ \text{N s}}.$$

(b) Average net force:

$$F_{\text{net,av}} = \frac{\Delta p}{\Delta t} = \frac{+3.00}{0.0200} = \boxed{+150\ \text{N}}.$$

(c) During contact, upward floor force N and downward weight mg give

$$N_{\text{av}} - mg = F_{\text{net,av}}.$$
$$N_{\text{av}} = 150 + (0.150)(9.80) = \boxed{151\ \text{N upwards}}$$

to three significant figures (unrounded value 151.47 N).

D | Multi-step challenges

Solution 18. Collision followed by an ascent

(a) Take right as positive. Because the trolleys stick together,

$$(0.500)(4.00) + (0.500)(0) = (1.00)v,$$

$$\boxed{v = 2.00\ \text{m s}^{-1}\ \text{right}}.$$

(b) After impact, mechanical energy is conserved on the frictionless incline:

$$\frac{1}{2}(1.00)(2.00)^2 = (1.00)(9.80)h,$$

$$\boxed{h = 0.204\ \text{m}}.$$

(c) During impact,

$$K_{\text{before}} = \frac{1}{2}(0.500)(4.00)^2 = 4.00\ \text{J},$$

$$K_{\text{after}} = \frac{1}{2}(1.00)(2.00)^2 = 2.00\ \text{J},$$

$$\boxed{\Delta K = K_{\text{after}} - K_{\text{before}} = -2.00\ \text{J}}.$$

Thus 2.00 J **of kinetic energy is transformed** during the collision; energy is subsequently conserved mechanically on the incline.

Solution 19. Force applied at an angle with friction

(a) Applied-force work:

$$W_{\text{applied}} = Fs\cos\theta = (50.0)(6.00)\cos 30.0^\circ = \boxed{260\ \text{J}}$$

(unrounded 259.808 J).

(b) Work by friction:

$$W_f = -fs = -(12.0)(6.00) = \boxed{-72.0\ \text{J}}.$$

(c) Weight and normal reaction do no work; hence

$$W_{\text{net}} = 259.808 - 72.0 = \boxed{188\ \text{J}}.$$

(d) From rest, $W_{\text{net}} = \frac{1}{2}mv^2$:

$$v = \sqrt{\frac{2W_{\text{net}}}{m}} = \sqrt{\frac{2(187.808)}{10.0}} = \boxed{6.13\ \text{m s}^{-1}}.$$

Keep unrounded values until the final step.

Solution 20. Head-on elastic collision

Take right as positive. Initially, $u_1 = +4.00$ and $u_2 = -2.00$ m s^{-1}. Momentum conservation gives

$$2.00(4.00) + 1.00(-2.00) = 2.00v_1 + 1.00v_2,$$
$$6.00 = 2.00v_1 + v_2. \tag{1}$$

For an elastic collision,

$$v_2 - v_1 = u_1 - u_2 = 4.00 - (-2.00) = 6.00. \tag{2}$$

Thus $v_2 = v_1 + 6.00$ and from (1),

$$6.00 = 2.00v_1 + (v_1 + 6.00),$$

$$\boxed{v_1 = 0, \qquad v_2 = +6.00 \text{ m s}^{-1}}.$$

Momentum check: $p_i = 6.00$ kg m s^{-1} and $p_f = (2)(0) + (1)(6) = 6.00$ kg m s^{-1}.

Energy check:

$$K_i = \frac{1}{2}(2.00)(4.00)^2 + \frac{1}{2}(1.00)(-2.00)^2 = 16.0 + 2.00 = 18.0 \text{ J},$$

$$K_f = \frac{1}{2}(2.00)(0)^2 + \frac{1}{2}(1.00)(6.00)^2 = 18.0 \text{ J}.$$

Both conserved.

Solution 21. Momentum in two dimensions

The remaining mass is $m_3 = 6.00 - 2.00 - 1.00 = 3.00$ kg. Take east as $+x$ and north as $+y$. Initial momentum is zero in each direction.

x direction:

$$0 = (2.00)(+3.00) + (1.00)(0) + (3.00)v_{3x},$$

$$\boxed{v_{3x} = -2.00 \text{ m s}^{-1}}.$$

y direction:

$$0 = (2.00)(0) + (1.00)(+4.00) + (3.00)v_{3y},$$

$$\boxed{v_{3y} = -\frac{4}{3} \text{ m s}^{-1} = -1.33 \text{ m s}^{-1}}.$$

Speed:

$$|\vec{v}_3| = \sqrt{(-2.00)^2 + \left(-\frac{4}{3}\right)^2} = \boxed{2.40 \text{ m s}^{-1}}.$$

Direction:

$$\theta = \tan^{-1}\left(\frac{4/3}{2}\right) = \boxed{33.7^\circ \text{ south of west}}.$$

Total momentum remains zero because the explosion provides internal impulses; kinetic energy increases from stored internal energy.

Solution 22. An experimental collision and energy audit

(a) Take right as positive:

$$p_i = (0.500)(1.20) + (0.300)(0) = 0.600 \text{ kg m s}^{-1},$$

$$p_f = (0.500)(0.750) + (0.300)(0.750) = 0.600 \text{ kg m s}^{-1}.$$

Measured values are consistent with momentum conservation.

(b) Initial kinetic energy:

$$K_i = \frac{1}{2}(0.500)(1.20)^2 = 0.360 \text{ J}.$$

Final kinetic energy:

$$K_f = \frac{1}{2}(0.500)(0.750)^2 + \frac{1}{2}(0.300)(0.750)^2 = 0.225 \text{ J}.$$

Therefore,

$$\Delta K = K_f - K_i = 0.225 - 0.360 = \boxed{-0.135 \text{ J}}.$$

$$\text{Percentage transformed} = \frac{0.135}{0.360} \times 100\% = \boxed{37.5\%}.$$

(c) The collision is **inelastic** because kinetic energy is not conserved; as both bodies have the same final velocity, it is consistent with a perfectly inelastic collision.

(d) One possibility is a small external friction impulse on the trolleys during measurement. Alternatively, finite velocity-measurement resolution may lead to an apparent difference. Momentum conservation refers to the isolated system, not to each trolley individually.

Curriculum reference: NSW Education Standards Authority, *Physics 11–12 Syllabus (2025)*, Year 11, *Fundamentals of mechanics — Momentum and energy*, outcome PY-11-01 and relevant Working scientifically outcomes. Official syllabus: https://curriculum.nsw.edu.au/learning-areas/science/physics-11-12-2025/content