H2 Physics (9478) WA1 Mechanics Notes

Quantities and Measurement • Kinematics • Dynamics • Equilibrium • Energy

HCI C1 2026 school materials + SEAB 2027 syllabus aligned

Exam Tip How to use this

This is a **WA revision document**, not a textbook. For each question, first identify the model: measurement, graph/SUVAT, force/Newton, moment/equilibrium, or energy. Then draw the minimum diagram, define a positive direction or pivot, write the conservation/law statement, substitute values with units, and check signs.

1 Scope and Source Coverage

WA topic	Syllabus outcomes covered	HCI source and exam evidence
Quantities and Measurement	1(a)-1(j): base/SI units, prefixes, derived units, homogeneity, estimates, errors and uncertainties, scalars/vectors, components	HCI Ch1 notes: derived unit and homogeneity examples, uncertainty checkpoint/discussion questions, vector addition and component practice.
Kinematics	3(a)-3(e), 5(b), 5(e): motion terms, graphs, SUVAT derivation/use, free fall, perpendicular projectile components, air resistance/terminal velocity	HCI Ch2 notes and worked examples: vector displacement, graph gradient/area, SUVAT, projectile motion, skydiver/terminal-velocity graphs.
Dynamics and Collisions	2(b), 3(f)-3(i), 6(a)-6(e): force types, mass/inertia, momentum, Newton's laws, $F = ma$, impulse, momentum conservation, elastic/inelastic collisions	HCI Ch3 notes and checkpoint solutions: average force from Δp, impulse as force-time area, system FBDs, slope resolving, collision learning points.
Equilibrium	2(c)-2(i), 5(a): Hooke's law, upthrust, moments, couples, centre of gravity, translational and rotational equilibrium, vector triangles/FBDs	HCI Ch4 notes and example solutions: spring, upthrust, three-force equilibrium, principle of moments, torque of a couple.
Energy	4(a)-4(e), 4(j)-4(n), 5(c)-5(d): energy stores/transfers, work, kinetic energy derivation, GPE, EPE, conservation of energy, power, efficiency	HCI Ch5 notes and worked examples: work-energy theorem, area under force-displacement/extension graphs, conservation with losses, power and efficiency. Field-line content is outside this WA unless explicitly taught.

2 Formula and Decision Bank

Formula / Method Bank

Topic	Key results	Use when / warning
Measurement	percentage uncertainty $= \frac{\Delta x}{x} \times 100\%$. Products/quotients: add fractional or percentage uncertainties. Powers: multiply fractional uncertainty by the power.	Absolute uncertainty has same unit as quantity; percentage uncertainty has no unit. For addition/subtraction, add **absolute** uncertainties, not percentage uncertainties.
Vectors	$A_x = A\cos\theta$, $A_y = A\sin\theta$; resultant by component addition.	Choose axes that simplify the problem: along slope, perpendicular to slope, horizontal/vertical for projectiles.
Graphs	s-t gradient = velocity; v-t gradient = acceleration; v-t area = displacement; force-time area = impulse; force-displacement area = work.	Area below the axis is negative displacement/impulse/-work. Do not confuse distance with displacement.
SUVAT	$v = u+at$, $s = ut+\frac{1}{2}at^2$, $v^2 = u^2+2as$, $s = \frac{1}{2}(u+v)t$.	Constant acceleration only. For free fall without air resistance, use $a = \pm g$ depending on positive direction.
Newton and momentum	$p = mv$, $\sum F = \frac{\Delta p}{\Delta t}$, constant mass: $\sum F = ma$, impulse $J = \Delta p = \int F dt$.	Always state positive direction. For systems, internal forces cancel; external resultant changes system momentum.
Collisions	Closed system: $m_1u_1+m_2u_2 = m_1v_1+m_2v_2$. Perfectly elastic: relative speed of approach = relative speed of separation.	Momentum is conserved for a closed system; kinetic energy is conserved only for elastic collisions.
Equilibrium	Translational: $\sum F_x = 0$, $\sum F_y = 0$. Rotational: $\sum \tau = 0$, moment $= Fd$. Couple torque = one force × perpendicular separation.	Pick pivot through unknown forces to remove their moments. For three-force equilibrium, forces are concurrent or form a closed vector triangle.
Energy	$W = Fs\cos\theta$; $E_k = \frac{1}{2}mv^2$; $\Delta E_p = mg\Delta h$; $E_{elastic} = \frac{1}{2}kx^2$; $P = \frac{E}{t} = Fv$; $\eta = \frac{\text{useful output}}{\text{total input}} \times 100\%$.	Energy is scalar. If non-conservative forces act, include work done by them or account for energy lost.

3 Quantities and Measurement

3.1 The mental model

Physics starts by turning reality into numbers. A quantity is only useful if it has a magnitude, a unit, and a clear measurement meaning. WA questions usually test whether you can **translate units, check dimensions, and judge uncertainty**.

Definition Physical quantity

A physical quantity is a measurable property expressed as numerical value × unit. Examples: mass $2.0\,\text{kg}$, speed $5.0\,\text{m}\,\text{s}^{-1}$, force $8.0\,\text{N}$.

3.2 SI units, derived units, prefixes

The six base quantities in this syllabus are mass kg, length m, time s, current A, temperature K, and amount of substance mol. Derived units come from equations. Example: from $F = ma$,

$$\text{N} = \text{kg}\,\text{m}\,\text{s}^{-2}.$$

Common prefixes: pico 10^{-12}, nano 10^{-9}, micro 10^{-6}, milli 10^{-3}, centi 10^{-2}, deci 10^{-1}, kilo 10^{3}, mega 10^{6}, giga 10^{9}, tera 10^{12}.

Exam Tip Homogeneity check

An equation is homogeneous if every term has the same base units. This checks whether an equation **could** be correct; it does not prove the numerical constants or signs are correct.

Worked Example Uncertainty in a derived quantity

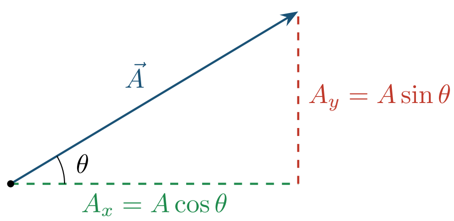
A rectangle has $l = (2.0 \pm 0.1)\,\mathrm{m}$, $b = (3.0 \pm 0.2)\,\mathrm{m}$. Area $A = lb = 6.0\,\mathrm{m}^2$.
Fractional uncertainty in A: $0.1/2.0 + 0.2/3.0 = 0.1167$, so percentage uncertainty $= 11.7\%$. Absolute uncertainty $= 0.1167 \times 6.0 = 0.7\,\mathrm{m}^2$.
Final: $A = (6.0 \pm 0.7)\,\mathrm{m}^2$.

3.3 Accuracy, precision, random and systematic errors

Term	Exam meaning
Precision	How close repeated readings are to each other; limited by random error and instrument resolution.
Accuracy	How close the measurement is to the true value; limited by systematic error and calibration.
Random error	Unpredictable scatter. Reduce by repeating and averaging.
Systematic error	Same-direction bias, e.g. zero error. Repeating does not remove it; calibrate or correct it.
Zero error	Instrument reads non-zero when true value is zero. Apply correction with sign carefully.

3.4 Scalars, vectors and components

Scalars have magnitude only: mass, time, temperature, energy, distance, speed. Vectors have magnitude and direction: displacement, velocity, acceleration, force, momentum.



Trap Vector trap

Never add vector magnitudes directly unless they are collinear and in the same direction. Resolve into components or use a vector triangle.

4 Kinematics

4.1 The mental model

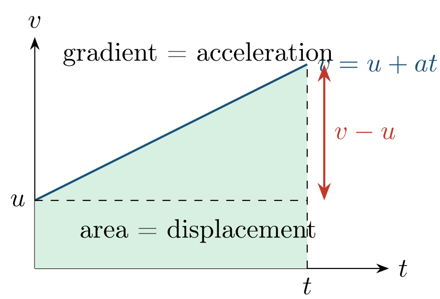
Kinematics describes motion without asking what caused it. The core question is: **what changes with time?** Position leads to displacement, displacement over time leads to velocity, and velocity over time leads to acceleration.

Definition Motion terms

Distance is total path length, a scalar. Displacement is change in position, a vector. Speed is rate of change of distance. Velocity is rate of change of displacement. Acceleration is rate of change of velocity.

4.2 Graphs are not pictures of paths

A motion graph is a coded story. Read the axes before interpreting shape.



Derivation SUVAT from definitions

For constant acceleration, gradient of the v-t graph gives

$$a = \frac{v-u}{t} \quad \Rightarrow \quad v = u + at.$$

Area under the same graph gives displacement:

$$s = \frac{1}{2}(u+v)t.$$

Substitute $v = u + at$: $s = ut + \frac{1}{2}at^2$. Eliminating t gives $v^2 = u^2 + 2as$. The equations are graph facts, not magic formulas.

Worked Example Vertical throw

A ball is thrown upwards at $12.0\,\mathrm{m\,s^{-1}}$. Taking upwards positive and $a = -9.81\,\mathrm{m\,s^{-2}}$, at the top $v = 0$.
$0 = 12.0 - 9.81t$, so $t = 1.22\,\mathrm{s}$.
$0^2 = 12.0^2 + 2(-9.81)s$, so $s = 7.34\,\mathrm{m}$.
The sign of a, not the sign of g, changed because we chose upwards as positive.

4.3 Projectiles: split one motion into two independent stories

Horizontal motion has constant velocity if air resistance is negligible. Vertical motion has constant acceleration g. Time connects the two directions.

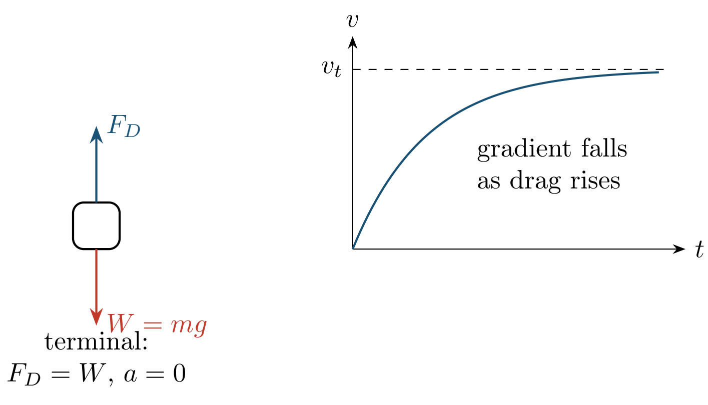
$$x = u_x t, \qquad y = u_y t + \frac{1}{2}a_y t^2, \qquad v_y = u_y + a_y t.$$

Exam Tip Projectile template

Resolve initial velocity first: $u_x = u\cos\theta$, $u_y = u\sin\theta$. Use vertical motion to find time or height. Then use horizontal motion to find range. Do not use the total launch speed in a vertical SUVAT equation.

4.4 Air resistance and terminal velocity

With drag, acceleration is not constant, so SUVAT generally fails. A falling object speeds up, drag increases, resultant force decreases, and acceleration decreases. At terminal velocity, drag plus upthrust balances weight, so resultant force is zero.



Trap When SUVAT fails

If the question mentions air resistance, drag, terminal velocity, or a curved v-t graph, do not blindly use SUVAT. Use forces/energy qualitatively and graph gradient/area instead.

5 Dynamics and Collisions

5.1 The mental model

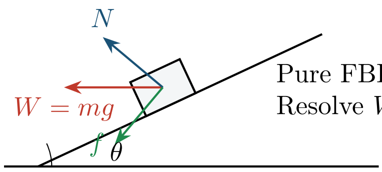
Dynamics explains why motion changes: a resultant external force changes momentum. For constant mass, that becomes $\sum F = ma$. Most WA mistakes come from drawing the wrong free-body diagram or choosing the wrong system.

Definition Newton's laws

1st law: velocity remains constant unless a resultant external force acts. 2nd law: resultant force is rate of change of momentum and acts in that direction. 3rd law: interacting bodies exert equal and opposite forces of the same type on each other.

5.2 Free-body diagram discipline

1. Isolate the body or system.
2. Draw only real forces acting *on* that body: weight, normal contact, tension, friction, drag, upthrust, applied force, spring force.
3. Choose axes along the expected motion or along constraints.
4. Resolve forces, then apply $\sum F = ma$ along each axis.



Trap Slope trap

On a slope, $mg\sin\theta$ and $mg\cos\theta$ are components of weight, not extra forces. If your FBD already shows mg, do not also count the components as separate forces in the same force equation.

Worked Example Newton's second law

A 2.0 kg block is pulled horizontally by 10 N, with friction 2 N opposing motion. Resultant force $= 10 - 2 = 8$ N.
$a = F/m = 8/2.0 = 4.0\,\mathrm{m\,s^{-2}}$ in the pulling direction.

5.3 Momentum, impulse and collisions

Momentum is a vector measure of "how hard motion is to stop": $p = mv$. Impulse is the change in momentum:

$$J = \Delta p = F_{avg}\Delta t = \text{area under a force-time graph.}$$

Worked Example Average force from change in momentum

A 0.150 kg ball rebounds from a wall. Take motion towards the wall as positive. It changes from $+20\,\mathrm{m\,s^{-1}}$ to $-15\,\mathrm{m\,s^{-1}}$ in 0.050 s.
$\Delta p = m(v - u) = 0.150(-15 - 20) = -5.25\,\mathrm{N\,s}$.
$F_{avg} = \Delta p/\Delta t = -5.25/0.050 = -105\,\mathrm{N}$. The negative sign means force is away from the wall.

Exam Tip Collision template

State: "For the closed system during the short collision, external impulse is negligible, so total momentum is conserved." Then write a signed momentum equation. Only add kinetic energy conservation if the collision is elastic or if the question explicitly tells you so.

6 Equilibrium

6.1 The mental model

Equilibrium means no acceleration and no angular acceleration. A body can have no resultant force but still rotate if there is a resultant torque; that is why moments matter.

Definition Equilibrium

A system is in equilibrium when $\sum F = 0$ and $\sum \tau = 0$. Translational equilibrium prevents acceleration of the centre of mass. Rotational equilibrium prevents angular acceleration.

6.2 Hooke's law and upthrust

Hooke's law: $F = kx$, where x is extension or compression from natural length. It only holds before the proportional limit. Upthrust is an upward fluid force due to pressure difference; for floating equilibrium, upthrust equals weight.

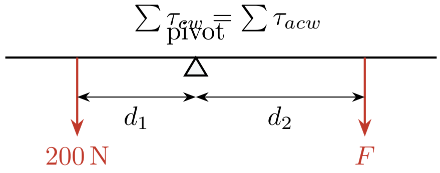
6.3 Moments and the principle of moments

Moment of a force about a pivot:

$$\tau = Fd,$$

where d is the perpendicular distance from the pivot to the force's line of action.

$$\sum \tau_{cw} = \sum \tau_{acw}$$



Exam Tip Pivot choice

Choose a pivot through an unknown force to make its moment zero. This is the fastest way to remove a support reaction or hinge force from the moment equation.

6.4 Three-force systems and vector triangles

If a body is in equilibrium under three non-parallel forces, the forces must be concurrent and can be represented by a closed vector triangle. This is why many equilibrium questions can be solved by resolving forces horizontally/vertically or by sine/cosine rule on the force triangle.

Trap Common moment mistakes

Use perpendicular distance to the line of action, not the length of the rod unless the force is perpendicular to the rod. Clockwise and anticlockwise signs must be consistent.

7 Energy

7.1 The mental model

Energy is a bookkeeping quantity: it tracks transfers between stores. Use energy when forces vary, paths are awkward, or you only care about initial and final states. Use Newton's laws when you need acceleration, time, or force details.

Definition Work

Work done by a force is the mechanical energy transferred by that force:

$$W = Fs\cos\theta.$$

For a variable force, work is area under the force-displacement graph.

Derivation Kinetic energy

For a constant resultant force in the direction of motion, $W = Fs$. From $F = ma$ and $v^2 = u^2 + 2as$,

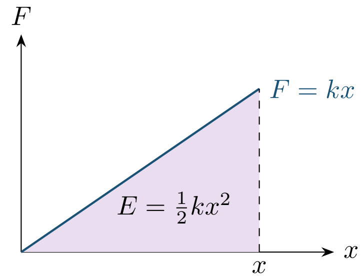
$$s = \frac{v^2 - u^2}{2a}, \qquad W = ma\left(\frac{v^2 - u^2}{2a}\right) = \frac{1}{2}m(v^2 - u^2).$$

Thus the change in kinetic energy is $\Delta E_k = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$.

7.2 Potential energy and conservation

Near Earth's surface, $\Delta E_p = mg\Delta h$. For a Hookean spring,

$$E_{elastic} = \text{area under } F\text{-}x \text{ graph} = \frac{1}{2}kx^2.$$



Worked Example Energy method

A 0.50 kg object falls 2.0 m from rest with negligible air resistance. Loss in GPE becomes KE:

$$mg\Delta h = \frac{1}{2}mv^2 \quad \Rightarrow \quad v = \sqrt{2g\Delta h} = 6.26\,\mathrm{m\,s^{-1}}.$$

Mass cancels because all objects in the same gravitational field gain the same speed change if air resistance is negligible.

7.3 Power and efficiency

Power is rate of energy transfer: $P = E/t$. Mechanical power is $P = Fv$ when the force is in the direction of velocity. Efficiency is

$$\eta = \frac{\text{useful energy output}}{\text{total energy input}} \times 100\%.$$

Losses do not destroy energy; they transfer it to less useful stores, usually thermal/internal energy and sound.

Trap Energy trap

Conservation of energy is always true, but conservation of *mechanical* energy requires no net work by non-conservative forces such as friction and drag. If friction acts, include work done against friction or energy lost.

8 Exam Pattern Bank

Pattern	**Trigger clues**	**Method skeleton**	**Marks/traps**
Unit/dimension check	"Show units", "homogeneous", derived unit	Convert each side to SI base units; compare dimensions term by term.	Homogeneity cannot prove constants.
Uncertainty propagation	product, quotient, power, repeated readings	Use absolute uncertainties for sums; fractional/percentage for products and quotients. Quote sensible s.f.	Do not mix absolute and percentage uncertainty.
Vector/resultant problem	displacement in stages, force components, inclined plane	Draw triangle or resolve into perpendicular components; add components; recombine.	Direction matters; state bearing/angle.
Motion graph	gradient, area, non-uniform acceleration	Read axes; gradient gives rate; area gives accumulated quantity. Split into simple shapes if needed.	Area below axis is negative. Distance may require absolute areas.
SUVAT/free fall	constant acceleration, vertical motion, no air resistance	Choose sign convention; list u, v, a, s, t; select equation missing unwanted variable.	Do not use if acceleration varies.
Projectile	horizontal plus vertical, launch angle, range/time	Resolve launch velocity; solve vertical for time/height; use horizontal constant velocity.	Same time in both directions.
Terminal velocity	air resistance, drag, speed-time curve	Compare weight, drag, upthrust; resultant force gives acceleration; at terminal $\sum F = 0$.	Terminal velocity is constant speed, not zero velocity.
FBD/Newton	block, lift, slope, connected objects	Isolate body/system; draw real forces; resolve; apply $\sum F = ma$.	Internal forces cancel only for whole system.
Impulse	force-time graph, collision duration, average force	Area under F-t graph = impulse = change in momentum.	Use signed momentum change.
Momentum conservation	collision/explosion, two bodies, closed system	State no net external impulse; write signed momentum equation before and after.	KE not always conserved.

Moments	beam, pivot, support reaction, balance	Choose pivot; calculate clockwise and anticlockwise moments; set equal if equilibrium.	Use perpendicular distance.
Three-force equilibrium	hanging object, strings, vector triangle	Resolve horizontal/vertical or draw closed force triangle.	Forces on same body only.
Energy conservation	speed from height, spring, friction/losses	Write initial stores + work input = final stores + losses.	Energy scalar; no sign direction, but height change matters.
Power/efficiency	motor, lift, useful output, losses	$P = E/t$ or $P = Fv$; efficiency = useful/total.	Convert kW, minutes, percentages.

9 Command Words and Answer Templates

Command	What earns marks
Define	Precise statement plus conditions and units where relevant. Example: moment = force times perpendicular distance from pivot to line of action.
Explain	Cause-effect chain using laws. Example: drag increases with speed, resultant force decreases, acceleration decreases, terminal velocity when forces balance.
Calculate	Formula, substitution with units, answer with correct s.f. and direction/sign where needed.
Sketch	Correct axes, labels, key shape, intercepts/gradient/area/terminal/asymptote where relevant.
State and apply	State law first, then use it in the specific context.
Compare	Identify similarity and difference using the same physical quantity.

Formula / Method Bank Physics answer templates

- **Graph:** axis meaning → gradient/area → numerical value/sign → unit.
- **Newton:** choose system → FBD → positive direction → $\sum F = ma$ → solve.
- **Momentum:** define closed system → signed before momentum = signed after momentum → solve → check KE only if asked.
- **Moments:** choose pivot → list clockwise/anticlockwise moments → set equal → solve reactions/forces.
- **Energy:** write initial stores + work input = final stores + losses → cancel/solve → interpret speed/height/efficiency.

10 Final WA Checklist

- Units: convert to SI before calculation; quote final unit and sensible significant figures.
- Directions: for vectors, momentum, impulse, force and acceleration, state positive direction.
- Diagrams: draw FBDs with real forces only; draw graph axes with physical quantities and units.
- Graphs: area/gradient interpretations are high-yield for kinematics, impulse and work.
- Conditions: SUVAT needs constant acceleration; Hooke's law needs proportional limit not exceeded; momentum conservation needs closed system/no net external impulse; mechanical energy conservation needs no non-conservative losses.
- Sanity checks: acceleration in free fall should be about $9.81\,\mathrm{m\,s^{-2}}$; efficiency cannot exceed 100%; terminal velocity means zero acceleration; a support reaction can be larger or smaller than weight depending on acceleration/other forces.