STEM SCHOOLS · GRADE 10 · SEMESTER 1 · PHYSICS MIDTERM

Measurement & Forces, from zero

This guide covers the two learning outcomes on your midterm: **PH 1.01 Measurement** and **PH 1.02 Newton's 3rd law**. It follows your school's slides (Mr. Hany Bouless for LO1, Mrs. Mona Shaalan for LO2) and the past midterm questions. Read it top to bottom. Each section ends with the traps that cost students marks.

60 minutes | MCQ + written answers | LO1 · sessions 01–04 | LO2 · sessions 07–08

YOUR STUDY PLAN · TICK AS YOU FINISH

PH 1.01 Measurement & Units

Make measurements precisely and accurately using a variety of measurement tools.

1.1 What a measurement is, and the systems of units

> **Measurement** is comparing an unknown quantity with a known quantity of the same kind (the *unit*) to find how many times the first contains the second.

Every measurement needs a number and a unit. "The table is 2 long" means nothing. "The table is 2 m long" does. A full measurement is: sign, magnitude, prefix, unit (for example −3.5 km).

> **Basic (fundamental) quantities** cannot be defined using other quantities. In mechanics there are three: **length [L]**, **mass [M]**, **time [T]**.

> **Derived quantities** are built from the basic ones. Examples: speed = length ÷ time, force = mass × length ÷ time².

Dimension vs unit: the dimension says *what kind* of quantity it is (length). The unit says *how much* (metre, foot). Don't confuse a quantity's symbol (`m` for mass) with a unit (`m` for metre).

QUANTITY	METRIC · MKS	FRENCH · CGS	BRITISH · FPS
Length	metre (m)	centimetre (cm)	foot (ft)
Mass	kilogram (kg)	gram (g)	pound (lb)
Time	second (s)	second (s)	second (s)

Exam clue: pounds, yards, feet, inches, miles per hour → the **British system**.

The 7 SI base units

#	QUANTITY	UNIT	SYMBOL
1	Length	metre	`m`
2	Mass	kilogram	`kg`
3	Time	second	`s`
4	Electric current	ampere	`A`
5	Absolute temperature	kelvin	`K`
6	Amount of substance	mole	`mol`
7	Luminous intensity	candela	`cd`

Common SI derived units

QUANTITY	UNIT	IN BASE UNITS
Area / volume	m^2 / m^3	m^2, m^3
Speed, velocity	m/s	$m \cdot s^{-1}$
Acceleration	m/s^2	$m \cdot s^{-2}$
Force, weight	newton (N)	$kg \cdot m \cdot s^{-2}$
Pressure	pascal (Pa) = N/m^2	$kg \cdot m^{-1} \cdot s^{-2}$
Energy, work	joule (J) = N·m	$kg \cdot m^2 \cdot s^{-2}$
Power	watt (W) = J/s	$kg \cdot m^2 \cdot s^{-3}$
Density	kg/m^3	$kg \cdot m^{-3}$

Standard metre: distance between two marks on a platinum–iridium rod kept at 0 °C at the International Bureau of Weights and Measures near Paris.

Standard kilogram: mass of a platinum–iridium cylinder kept at 0 °C, same place. **Second:** 1/86 400 of the average solar day.

Trap: "Why is there no SI base unit for area?" Because area can be written in terms of a base unit (m^2). It is derived, not basic.

1.2 Prefixes and unit conversion

PREFIX	SYMBOL	× 10^n	PREFIX	SYMBOL	× 10^n
tera	T	10^{12}	deci	d	10^{-1}
giga	G	10^9	centi	c	10^{-2}
mega	M	10^6	milli	m	10^{-3}
kilo	k	10^3	micro	μ	10^{-6}
hecto	h	10^2	nano	n	10^{-9}
deca	da	10^1	pico / femto	p / f	10^{-12} / 10^{-15}

Two methods your teacher uses

Method 1 · Staircase (move the decimal). Going to a smaller unit, the number gets bigger.

`2.5 m = 250 cm · 0.5 kg = 500 g · 120 mm = 12 cm · 354 mL = 0.354 L`

Method 2 · Conversion factors. Multiply by a fraction equal to 1, arranged so the old unit cancels.

`8 mm × (10⁻³ m / 1 mm) × (1 cm / 10⁻² m) = 0.8 cm`

1. Write the start and the destination: `62.0 in → ? cm`
2. Find the equality: `1 in = 2.54 cm`
3. Multiply so units cancel: `62.0 in × 2.54 cm / 1 in = 157.48 cm`
4. Check the unit and round sensibly: **157.5 cm**

Equalities to memorise

1 in = 2.54 cm
1 ft = 12 in = 30.48 cm · 1 yard = 3 ft

1 mile = 1609 m
= 5280 ft

1 lb ≈ 0.454 kg
1 ounce (oz) = 28.35 g

$1\ h = 3600\ s$
1 day = 86 400 s

$1\ mL = 1\ cm^3$
1 L = 1000 cm^3 = 10^{-3} m^3

$1\ g/cm^3 = 1000\ kg/m^3$
so g/cm^3 is the **larger** unit

Speed shortcut: km/h → m/s, divide by 3.6 (×1000 m, ÷3600 s). $72\ km/h = 20\ m/s$ · $90\ km/h = 25\ m/s$ · $6\ km/min = 100\ m/s$ · $240\ m/min = 4\ m/s$
$55\ mi/h \times 1609\ m/mi \div 3600\ s/h \approx 25\ m/s$ · $60\ mi/h = 88\ ft/s$

Trap: squared and cubed units convert with the power too. $1\ cm^3 = (10^{-2}\ m)^3 = 10^{-6}\ m^3$, not $10^{-2}\ m^3$.

1.3 Measuring tools and density

TOOL	SMALLEST READING	USE IT FOR
Metre ruler	$1\ mm\ (0.1\ cm)$	Lengths of books, tables
Vernier caliper	$\approx 0.1\ mm$ or better	Outer/inner diameters, small blocks
Micrometer screw gauge	$0.01\ mm$	Wire diameter, thin sheets
Balance	depends on model	Mass
Graduated cylinder	depends on scale	Liquid volume, irregular solids (displacement)

Micrometer steps: open the spindle with the ratchet, put the object in, tighten with the ratchet, lock, read.

Vernier steps: open the main jaws with the wheel, put the object in, tighten the screw, read.

$$\rho = m / V = m / (L \times W \times H)$$

Density of a block. Units g/cm^3 or kg/m^3. Water = 1 g/cm^3; aluminium = 2.7 g/cm^3; steel = 7.8 g/cm^3.

Exam clue: "accuracy of 0.01 mm" → **micrometer**.

1.4 Measurement errors, accuracy and precision

Why errors happen

1. Choosing the wrong tool.
2. Instrument faults: old device, weak battery, weak magnet, **zero error**.
3. Environment: temperature, humidity, air currents.
4. Human error: **parallax** (reading the scale from an angle) and mathematical mistakes.

> **Systematic error**: the same in every reading, always in one direction. Caused by the instrument or method (zero error, a scale reading 1.5 kg too high). Repeating does not remove it. Fix the tool or correct the readings.

> **Random error**: changes unpredictably from reading to reading (parallax, reaction time). Reduced by taking many readings and averaging.

Direct vs indirect measurement

POINT	DIRECT	INDIRECT
Measuring steps	One tool, one step	Two or more measurements
Maths	None	A formula combines them
Errors	One error	Errors add up
Example	Volume with a cylinder; liquid density with a hydrometer	Volume = L × W × H; density = m ÷ V

Error formulas

$\Delta x = | x_0 - x |$
Absolute error. x_0 = real value, x = measured value. Has the same unit as x.

$r = \Delta x / x_0$ (× 100%)
Relative error. No unit. Smaller r = more accurate. r is a better measure of accuracy than Δx.

$\Delta x = r \times x_0$
Go back from relative to absolute error.

IF THE RESULT IS FOUND BY…	THEN…	EXAMPLE
Adding or subtracting	Add the **absolute** errors: $\Delta x = \Delta x_1 + \Delta x_2$	Total length; coin volume by water displacement
Multiplying or dividing	Add the **relative** errors: $r = r_1 + r_2$	Area = L × W; density = m ÷ V
A power x^n	Multiply r by the power: $r = n \cdot \Delta x/x_0$	Cube V = L^3 → 3r; circle area ∝ d^2 → 2r
A root $\sqrt[n]{x}$	Divide by n: $r = (1/n) \cdot \Delta x/x_0$	√x → ½ r

Always add, never subtract errors. Even when you subtract the values, the errors add. Constants like ½, π, 4/3 have no error.

Worked example 1 (direct). Pencil: true 10 cm, measured 9.9 cm. Class: true 9.11 m, measured 9.13 m.
$\text{Pencil: } \Delta x = 0.1 \text{ cm}, r = 0.1/10 = 1\%$
$\text{Class: } \Delta x = 0.02 \text{ m} = 2 \text{ cm}, r = 0.02/9.11 = 0.22\%$
The class measurement has a bigger absolute error but is **more accurate** (smaller r).

Worked example 2 (multiplying). Rectangle L = (6 ± 0.1) m, W = (5 ± 0.2) m. Find the area.
$r_1 = 0.1/6 = 0.017 \cdot r_2 = 0.2/5 = 0.04 \cdot r = 0.057$
$A_0 = 30 \text{ m}^2 \cdot \Delta A = 0.057 \times 30 = 1.7 \text{ m}^2 \rightarrow A = (30 \pm 1.7) \text{ m}^2$

Worked example 3 (power). Cube side 10 cm ± 2 mm. Find ΔV.
$\text{Convert first: } 2 \text{ mm} = 0.2 \text{ cm} \cdot r_L = 0.2/10 = 0.02 \cdot r_V = 3 \times 0.02 = 0.06$
$V_0 = 1000 \text{ cm}^3 \cdot \Delta V = 0.06 \times 1000 = 60 \text{ cm}^3$

Worked example 4 (systematic error). A boy of true mass 36.5 kg reads 38 kg on a faulty scale. His sister reads 14 kg. The scale adds 1.5 kg every time, so her real mass = 14 − 1.5 = **12.5 kg**.

Accuracy vs precision

Accuracy: how close the readings are to the **true value**.

Precision: how close the readings are to **each other** when repeated.



Accurate + precise

3.11, 3.12, 3.12, 3.10



Precise, not accurate

3.77, 3.81, 3.76, 3.80



Accurate, not precise

3.04, 3.20, 3.13, 3.07



Neither

3.01, 3.89, 3.50, 5.99

True density = 3.11 g/cm³ (example from your slides).

Trap: readings of g = 10.52, 10.52, 10.53, 10.52 m/s² are **precise but not accurate** (true g ≈ 9.8). Close together ≠ correct.

1.5 Dimensional analysis

Dimension of a quantity: the powers to which **[M]**, **[L]**, **[T]** are raised to express it. In general $[X] = M^a L^b T^c$.

QUANTITY	FORMULA	DIMENSION	SI UNIT
Area / Volume	$L \cdot w$ / $L \cdot w \cdot h$	L^2 / L^3	m^2 / m^3
Density	m / V	$M L^{-3}$	kg m^{-3}
Velocity	d / t	$L T^{-1}$	m s^{-1}
Acceleration	v / t	$L T^{-2}$	m s^{-2}
Force, weight	$m a$, $m g$	$M L T^{-2}$	N
Momentum	$m v$	$M L T^{-1}$	kg m s^{-1}
Work, energy, KE, PE	$F d$, $\frac{1}{2}mv^2$, mgh	$M L^2 T^{-2}$	J
Power	W / t	$M L^2 T^{-3}$	W
Pressure, stress	F / A	$M L^{-1} T^{-2}$	Pa
Frequency	$1 / T$	T^{-1}	Hz = s^{-1}
Strain, angle	$\Delta L / L_o$	dimensionless	none

The rules

- You can only add or subtract quantities with **the same dimensions**.
- Every term on both sides of a correct equation has **the same dimensions**.
- Pure numbers (½, 2, π) have **no dimensions**. Dimensional analysis cannot find their values.
- An equation can be dimensionally correct and still physically wrong. KE = mv^2 has correct dimensions but is missing the ½.

Three question types

1 · Check a law. Is $v = v_o + at$ correct?
$[v] = LT^{-1} \cdot [v_o] = LT^{-1} \cdot [at] = LT^{-2} \times T = LT^{-1}$ → all terms match ✓

2 · Find an unknown's dimension. X = YZ, [X] = M^2LT^{-2}, [Y] = ML^4T^{-2}. Find [Z].
$Z = X/Y \rightarrow [Z] = M^{2-1}\ L^{1-4}\ T^{-2+2} = M\ L^{-3}$ (subtract powers when dividing)

3 · Find the unit of a constant. v = at^2 + bt^3. Each term must be m/s.
$a = v/t^2 \rightarrow m/s^3 \cdot b = v/t^3 \rightarrow m/s^4$
Gravity: $F = GMm/d^2 \rightarrow G = Fd^2/(Mm) \rightarrow [G] = MLT^{-2} \cdot L^2 / M^2 = M^{-1}L^3T^{-2}$
Magnetic force $F = BIL$ with I in C/s: $B = F/(IL) \rightarrow 1\ T = kg \cdot C^{-1} \cdot s^{-1} = N \cdot s/(C \cdot m)$

Power rules you'll need: multiply → add powers; divide → subtract powers; square root → halve powers. $(ML^2T^{-2})^{1/2} = M^{1/2}\ L\ T^{-1}$

LO1 QUICK CHECK · TAP TO REVEAL

▼ **0.1 mg in kg?**

$0.1 \times 10^{-3}\ g = 10^{-4}\ g = 10^{-7}\ kg$

▼ **A zero error on an ammeter causes which error?**

Systematic. It shifts every reading by the same amount.

▼ **Radius error 1%. Error in sphere volume?**

$V = 4/3\ \pi r^3 \rightarrow 3 \times 1\% = 3\%$.

▼ **Dimensions of Planck's constant (E = hf)?**

$h = E/f = ML^2T^{-2} \times T = ML^2T^{-1}$

PH 1.02 Forces & Newton's 3rd Law

Use Newton's 3rd law to identify the forces of interaction that exist between pairs of objects (Newtonian pairs).

2.1 What a force is, and the types of force

Force is a push or a pull from an interaction between two objects. It is a **vector** (it has size and direction). **1 newton** is the force that gives a 1 kg mass an acceleration of 1 m/s². In SI, a force is numerically equal to the acceleration it gives the standard kilogram.

$F = m\ a$

1 N = 1 kg·m/s²

$W = F_g = m\ g$

g = 9.8 N/kg (m/s²). Weight acts vertically down.

FORCE	SYMBOL	DIRECTION	KEY FACT
Weight (gravity)	$W = mg$	Straight down, toward Earth's centre	Acts even with no contact
Normal	N, F_N	Perpendicular to the surface, pushing out	Flat table, nothing else acting: N = mg. A wall pushing on you is also normal force.
Tension	T	Along the rope, pulling away from the object	Same all along a light rope ($T_1 = T_2$). Equals the weight hanging from it at rest.
Friction	f, F_f	Along the surface, opposite to motion or attempted motion	Constant velocity → friction = applied force
Air resistance	F_{air}	Opposite to motion through air	Usually neglected; matters at high speed
Spring	F_s	Back toward the rest position	Size ∝ stretch or compression
Applied	F_{app}	Whatever way the push/pull goes	From a person or object

Mass (kg): amount of matter. The same everywhere. Measured with an **equal-arm balance**.

Weight (N): the pull of gravity, W = mg. Changes with g. Measured with a **spring scale**.

Trap (past midterm): an object balances 12 kg on a balance and reads 12 kg on a spring scale. On the Moon (g ÷ 6): the balance still reads **12 kg** (both sides change together), the spring scale reads **2 kg**.

2.2 Equilibrium: balanced and unbalanced forces

$\text{Equilibrium} \Leftrightarrow \Sigma F = 0 \Leftrightarrow a = 0$

Add forces with signs: up/right +, down/left −. Do it separately for vertical and horizontal.

Static equilibrium: net force zero and the object is **at rest** (v = 0). Book on a table, a hanging lamp.

Dynamic equilibrium: net force zero and the object moves at **constant velocity**. A car at steady speed: engine force forward = friction backward. A skydiver at terminal velocity.

Balanced forces: equal in size, opposite in direction. Stays at rest or keeps the same speed and direction.

Unbalanced forces: one side is bigger. The object speeds up, slows down, changes direction or stops, in the direction of the bigger force.

Example (slides). A 5 kg mass hangs at rest from force C. ΣF = 0 → $C - mg = 0 \rightarrow C = 5 \times 9.8 = 49\ N$

Example (past midterm). A block slides at **constant velocity**. 5 N pulls right, 3 N pulls left, and friction is the only other horizontal force.

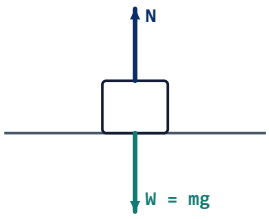
$5 - 3 - f = 0 \rightarrow f = 2\ N,\ \text{leftward}$

Example (exam guide). A plane flies straight at constant speed → **thrust = drag** and **lift = weight**.

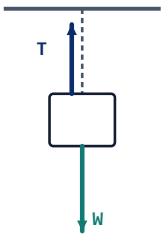
Remember: constant velocity means **zero** net force, not "a force in the direction of motion". The least number of **unequal** forces that can balance is **3**.

2.3 Free-body diagrams

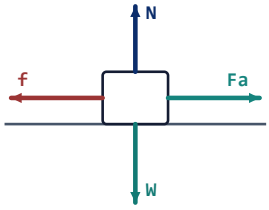
1. Draw the object as a box or dot, **alone**.
2. Draw only forces acting **on** it, as arrows starting at the object.
3. Arrow length shows size; arrow direction shows direction. Equal forces get equal arrows.
4. Label each arrow (W, N, T, f, F_app) and check: is ΣF = 0?



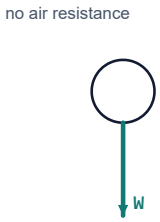
Book on a table
2 forces. Weight W (Earth on book) and normal force N (table on book).



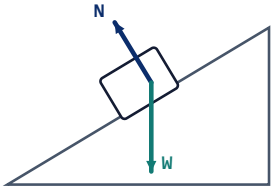
Hanging block
2 forces. Tension T (string on block) up, weight W down.



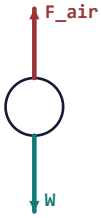
Pulled at constant velocity
4 forces. W down, N up, applied force Fa forward, friction f backward.



Falling object
1 force: weight only.



Box on a smooth incline
2 forces (frictionless). Weight W straight down.



Skydiver at terminal speed
2 forces. Air resistance up, weight down.

Trap: a ball thrown upward (no air resistance) has **only weight** acting on it, on the way up, at the top and on the way down. There is no "upward force of the throw" once it leaves the hand.

2.4 Newton's 3rd law and Newtonian pairs

> **Newton's 3rd law:** if object A exerts a force on object B, then B exerts a force on A that is **equal in size** and **opposite in direction**. "For every action there is an equal and opposite reaction."

F_A on B = − F_B on A

Always true: at rest, moving, speeding up, any mass.

Four checks for a real action–reaction pair

1. The two forces act on two different objects.
2. They are the **same type** of force (both gravity, both contact...).
3. They are **equal in size**.
4. They are **opposite in direction**, and appear and vanish together.

Naming trick: write a pair as "A on B" and "B on A". Just swap the names.
Hand pushes desk ↔ desk pushes hand.
Foot pushes ground backward ↔ ground pushes foot forward.

Why they don't cancel

Forces only cancel when they act on the **same** object. Action and reaction act on **different** objects, so each object feels only one of them. Their resultant is not used to judge either object's motion.

The classic: a book resting on a table.
The book's weight W and the table's normal force N are equal and opposite, but they are **not** a 3rd-law pair: both act on the book, and they are different types. They balance because of equilibrium. The real pairs are:
① Earth pulls book down ↔ book pulls Earth up (gravity).
② Book pushes table down ↔ table pushes book up (contact).

SITUATION	ACTION	REACTION
Fish swimming	Fins push water backward	Water pushes fish forward
Bird flying	Wings push air down	Air pushes bird up
Rocket	Rocket pushes hot gases down	Gases push rocket up
Kangaroo jump	Legs push ground	Ground pushes kangaroo, **equal** force
Hammer and nail	Hammer pushes nail	Nail pushes hammer (slows it down)
Rifle firing	Rifle pushes bullet forward	Bullet pushes rifle back (recoil)
Earth and Moon	Earth pulls Moon (F)	Moon pulls Earth, also F (causes tides)
Balloon	Earth pulls balloon 20 N down	Balloon pulls Earth 20 N up

Equal forces, different effects

Same force, different mass, so different acceleration (`a = F/m`). The firefly and the bus feel **the same force**; the firefly has tiny mass, so its acceleration (and the mess) is huge. The rifle has much more mass than the bullet, so its **acceleration is smaller**.

Horse and cart: horse pulls cart, cart pulls horse back equally. The system moves because the horse pushes backward on the **ground**, and the ground (an outside object) pushes the horse forward.

Stacked books. Book A (4 N) sits on book B (6 N) on a table. Both are at rest.
Forces on B: its weight 6 N ↓, A pushes down 4 N ↓, table pushes up 10 N ↑. Net force on B = **0**. Three forces act on B.
Pairs: A on B (4 N ↓) ↔ B on A (4 N ↑); B on table (10 N ↓) ↔ table on B (10 N ↑).

Spring scale with a 10 N weight on each end (over pulleys): it reads **10 N**, not 20 N. One weight is the pull; the other just holds the scale still. Kent pulling a rope tied to a wall or to an elephant: the scale reads 500 N in both cases.

Trap: "The nail goes in because the block's push on the nail is **less than** the hammer's push on the nail." Those two forces act on the same object (the nail), so they can differ. The pair "nail on block ↔ block on nail" is still equal.

LO2 QUICK CHECK · TAP TO REVEAL

▼ **A 50 kg player kicks a 25 g ball with 25 N east. Force on the player?**

25 N west. Mass doesn't change the size of the pair.

▼ **A man pushes a chair with 50 N. When does the chair push back with 50 N?**

Always: at rest, at constant velocity or accelerating.

▼ **The chair moves at constant velocity. Friction?**

50 N, because ΣF = 0.

▼ **Reaction to gravity on a block hanging from a string?**

The block pulls the Earth (up). Not the string's tension.

LAST LOOK BEFORE THE EXAM

One-page formula sheet

UNITS

- Basic: L (m), M (kg), T (s). 7 SI base units.
- k 10^{3} · M 10^{6} · G 10^{9} · c 10^{-2} · m 10^{-3} · μ 10^{-6} · n 10^{-9} · p 10^{-12}
- km/h ÷ 3.6 = m/s · 1 in = 2.54 cm · 1 mi = 1609 m
- 1 mL = 1 cm^{3} · 1 g/cm^{3} = 1000 kg/m^{3}

DIMENSIONS

- v LT^{-1} · a LT^{-2} · F MLT^{-2} · p MLT^{-1}
- E, W $ML^{2}T^{-2}$ · P $ML^{2}T^{-3}$ · Pa $ML^{-1}T^{-2}$ · ρ ML^{-3}
- Same dimensions on both sides; can't find ½ or π.
- Micrometer 0.01 mm · Vernier ≈ 0.1 mm · ruler 1 mm

NEWTON'S 3RD LAW

- F(A on B) = −F(B on A), always
- Different objects · same type · equal · opposite
- Pairs never cancel (different objects)
- W and N on a book are **not** a pair
- Equal force, smaller mass → bigger acceleration

ERRORS

- $\Delta x = |x_0 - x| \cdot r = \Delta x / x_0$
- + or − → add Δx · × or ÷ → add r
- x^{n} → n·r · √x → ½ r · constants: no error
- Systematic: same each time (zero error). Random: reduce by averaging.
- Accuracy → true value. Precision → each other.

FORCES

- $F = ma$ · $W = mg$, g = 9.8 N/kg
- Normal ⊥ surface · friction opposes motion · tension along rope
- Equilibrium: ΣF = 0 (rest = static, constant v = dynamic)
- Balance → mass; spring scale → weight

EXAM HABITS

- Convert units **before** calculating errors.
- Write the formula, substitute, give the unit.
- Eliminate wrong options first in MCQs.
- Answer every question. A blank scores zero.

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