1.1 — Complete Hard Practice Set

Covers SI base and derived units, the full unit conversion method, area and volume scaling, exotic chained conversions, and packing fraction problems. Built at exam difficulty, not textbook difficulty. Only a basic calculator allowed, no scientific notation shortcuts.

Section A — SI Base & Derived Units

Tests whether you actually know which units are base units and which are built from them, not just whether you can recite the list.

Problem 1

Conceptual — Base vs Derived

Classify each of the following as a base unit or a derived unit, and if derived, write its expression in terms of base units: (a) the kelvin, (b) the newton, (c) the coulomb, (d) the pascal.

Problem 2

Conceptual — Building a Derived Unit

Power is defined as energy divided by time. Starting from the base units for mass, length, and time, derive the full base-unit expression for the watt (the SI unit of power). Show every step, not just the final answer.

Problem 3

Conceptual — Reverse Engineering

A quantity has the derived unit $kg \cdot m^2/s^3$. Using the table of derived units from class, identify what physical quantity this unit represents, and explain how you arrived at that answer using the base units alone.

Section B — Unit Conversion (Bridge Method)

Every conversion factor equals 1. Find the bridge, make the ratio, cancel the unit. These problems test whether that method holds up under pressure.

Problem 4

Linear Conversion

Convert 7.4 kilometers to centimeters. Show the bridge and the full ratio chain you used — do not skip directly to an answer using a single combined factor.

Problem 5

Metric Ladder, Multi-Step

Convert 0.0032 kilograms to micrograms. State how many steps you are moving on the metric ladder and in which direction, before doing the arithmetic.

Problem 6

Squared Bridge (Area)

A square plot of land measures 2.5 m^2. Convert this area to square centimeters. Remember: you must square the entire bridge, not just the number.

Problem 7

Cubed Bridge (Volume)

A storage tank has a volume of 0.75 cubic meters. Convert this volume to cubic centimeters. Show why the conversion factor for volume is the cube of the linear conversion factor.

Section C — Extracting From Tables & Graphs

The value is never just sitting there waiting for you. Read the right column, read the right axis, then convert.

Trial	Distance (km)	Time (min)	Mass (g)
A	3.20	12.5	450
B	7.85	28.0	1,200
C	2.03	9.4	75
D	6.40	21.0	3,600

Problem 8

Table Extraction, Multi-Step

Using Trial B from the table above, find the average speed of the object in meters per second. You will need to convert both the distance and the time before dividing.

Problem 9

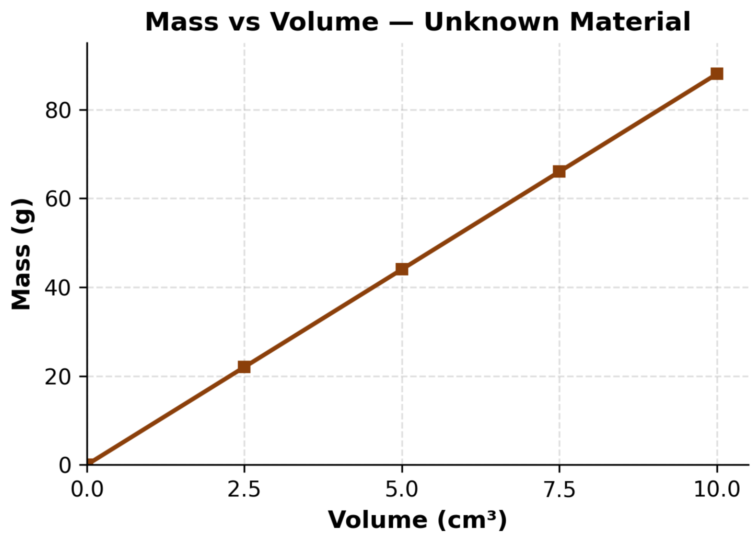
Table Extraction, Cross-Reference

Using Trial D from the table above, convert the mass to kilograms AND the distance to centimeters in the same response. Show both conversions fully.

Problem 10

Graph Reading, Slope as Speed

Using the graph above, calculate the slope of the line in meters per second. Then convert that speed to kilometers per hour.



Problem 11

Graph Reading, Non-Trivial Gridlines

Using the graph above, read the mass of the material at a volume of 7.5 cm^3. Convert that mass reading from grams to kilograms.

Section D — Exotic Chained Conversions

The realistic test version: more than one conversion factor chained together, often through units you don't normally work with.

Problem 12

Chained Conversion, Three Factors

A car travels at 95 kilometers per hour. Convert this speed to centimeters per minute. This requires at least three separate conversion factors chained together — identify each one before calculating.

Problem 13

Chained Conversion, Exotic Units

1 "sprint" is defined as 47 meters (one full length of a swimming pool, give or take). A runner moves at 6.2 meters per second. Express this speed in sprints per hour.

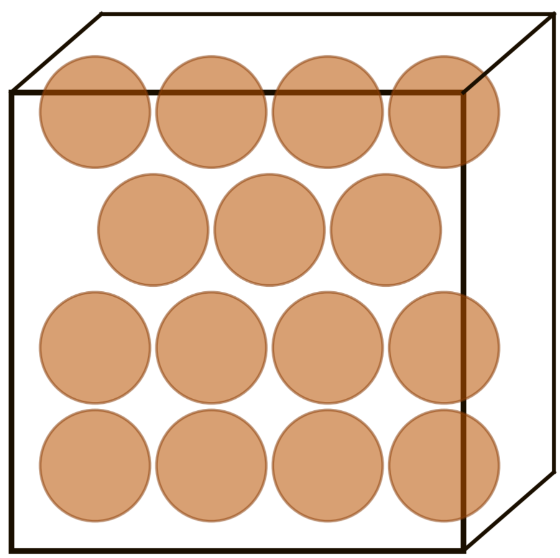
Problem 14

Chained Conversion, Hardest Version

1 "reel" of film lasts 11 minutes. A signal travels at 2.1×10^4 centimeters per second. Express this speed in kilometers per reel. Show every conversion factor used, in order.

Section E — Packing Fractions

Not every cubic centimeter of a container actually gets filled. Packing fraction tells you how much of the space is real material versus gaps.



Cube volume = 1000 cm³ | Each sphere = 4.2 cm³

Problem 15

Packing Fraction, Direct

A cube has a volume of 1000 cm^3. It is filled with identical spheres at the densest possible packing fraction, approximately 0.74. If each sphere has a volume of 4.2 cm^3, approximately how many spheres fit inside the cube?

Problem 16

Packing Fraction, Reverse

A container with a volume of 2,400 cm^3 is filled with 310 identical spheres at the densest packing fraction (0.74). Find the volume of a single sphere.

Problem 17

Packing Fraction, Combined With Conversion

A cubic storage container measures 0.5 meters on each side. It is filled with spherical beads, each with a volume of 1.8 cm^3, at a packing fraction of 0.74. First convert the container's volume to cubic centimeters, then find approximately how many beads fit inside.

Answer Key — 1.1 Complete Hard Practice Set

Full worked solutions for every problem.

Problem 1 — Solution

(a) Kelvin — **base unit** (one of the seven SI base units, measures temperature)

(b) Newton — **derived unit**, expressed as $kg \cdot m/s^2$ (from F = ma)

(c) Coulomb — **derived unit**, expressed as A·s (current × time)

(d) Pascal — **derived unit**, expressed as $kg/(m \cdot s^2)$ (force/area = $(kg \cdot m/s^2)/m^2$)

Common error: assuming any unit with a special name (like the newton) must be a base unit. A special name does not mean base — it's still built from the seven base units underneath.

Problem 2 — Solution

Power = Energy / Time

Energy (joule) = $kg \cdot m^2/s^2$ (mass × length^2 / time^2, from work = force × distance)

Power = $(kg \cdot m^2/s^2)$ / s = $\mathbf{kg \cdot m^2/s^3}$

Common error: stopping at the energy unit ($kg \cdot m^2/s^2$) and forgetting to divide by the additional factor of time required for power specifically.

Problem 3 — Solution

$kg \cdot m^2/s^3$ matches the base-unit expression for **power (the watt)**

Reasoning: mass × length^2 / time^3 is exactly the joule ($kg \cdot m^2/s^2$) divided by one more factor of time — which is the definition of power.

Common error: confusing this with energy ($kg \cdot m^2/s^2$) by miscounting the power of seconds in the denominator.

Problem 4 — Solution

Bridge: 1 km = 1000 m, and 1 m = 100 cm

7.4 km × (1000 m / 1 km) × (100 cm / 1 m) = 7.4 × 1000 × 100

= **740,000 cm**

Common error: trying to convert km directly to cm using a single memorized factor instead of chaining km→m→cm, which leads to errors when the factor is misremembered.

Problem 5 — Solution

kg to µg: kilo is 3 steps above base, micro is 6 steps below base

Total steps = 3 + 6 = 9 steps down the ladder

0.0032 kg × 10^9 = **3,200,000 µg**

Common error: jumping straight from kilo to micro without counting all 9 steps, often only counting 6 (the micro distance from base) and forgetting the extra 3 steps from kilo down to base first.

Problem 6 — Solution

Bridge: 1 m = 100 cm, so 1 m^2 = $(100\ cm)^2$ = 10,000 cm^2

$2.5\ m^2 \times 10{,}000 =$ **$25{,}000\ cm^2$**

Common error: multiplying by 100 instead of 10,000 — forgetting that an area conversion requires squaring the entire bridge, not just using the linear factor.

Problem 7 — Solution

Bridge: 1 m = 100 cm, so $1\ m^3 = (100\ cm)^3 = 1{,}000{,}000\ cm^3$

$0.75\ m^3 \times 1{,}000{,}000 =$ **$750{,}000\ cm^3$**

Common error: using the area factor (10,000) instead of the volume factor (1,000,000), or cubing only the exponent without cubing the coefficient correctly.

Problem 8 — Solution

Trial B: distance = 7.85 km, time = 28.0 min

Convert distance: 7.85 km × 1000 = 7,850 m

Convert time: 28.0 min × 60 = 1,680 s

Speed = 7,850 m / 1,680 s = **4.67 m/s**

Common error: dividing the unconverted km and min values directly, producing a number with no meaningful physical unit attached to it.

Problem 9 — Solution

Trial D: mass = 3,600 g, distance = 6.40 km

Mass: 3,600 g × (1 kg / 1000 g) = **3.6 kg**

Distance: 6.40 km × (100,000 cm / 1 km) = **640,000 cm**

Common error: applying the same conversion factor to both quantities even though mass and distance require completely different bridges.

Problem 10 — Solution

Slope = rise/run = (90 m - 0 m) / (5 s - 0 s) = 18 m/s

Convert: 18 m/s × (1 km/1000 m) × (3600 s/1 hr) = 18 × 3.6 = **64.8 km/hr**

Common error: reading a single point off the graph as the speed instead of calculating slope (rise over run) between two points first.

Problem 11 — Solution

Reading the graph at volume = $7.5\ cm^3$: mass = 66 g

66 g × (1 kg / 1000 g) = **0.066 kg**

Common error: misreading the value at a gridline that isn't a whole number, especially when the x-axis is spaced in increments of 2.5 instead of 1.

Problem 12 — Solution

95 km/hr × (1000 m / 1 km) = 95,000 m/hr

95,000 m/hr × (100 cm / 1 m) = 9,500,000 cm/hr

9,500,000 cm/hr × (1 hr / 60 min) = **158,333.3 cm/min**

Common error: only converting km to cm and forgetting to also convert the time unit from hours to minutes, leaving a mismatched compound unit.

Problem 13 — Solution

6.2 m/s × (1 sprint / 47 m) = 0.1319 sprints/s

0.1319 sprints/s × (3600 s / 1 hr) = ≈ **474.9 sprints/hr**

Common error: treating the exotic unit (sprint) as if it needs a completely new method, when it's just one more conversion factor in the same chain — the bridge is just less familiar, not more difficult.

Problem 14 — Solution

2.1×10^4 cm/s × (1 m / 100 cm) = 2.1×10^2 m/s = 210 m/s

210 m/s × (1 km / 1000 m) = 0.21 km/s

0.21 km/s × (60 s / 1 min) × (11 min / 1 reel) = 0.21 × 60 × 11

= **138.6 km/reel**

Common error: losing track of which direction each conversion factor needs to flip when chaining four or more factors together — always check that the unit you want to cancel is on the correct side of each fraction before moving to the next step.

Problem 15 — Solution

Usable volume = cube volume × packing fraction = 1000 cm^3 × 0.74 = 740 cm^3

Number of spheres = usable volume / volume per sphere = 740 / 4.2

= ≈ **176 spheres**

Common error: dividing the full cube volume (1000 cm^3) by the sphere volume without first multiplying by the packing fraction, which overestimates how many spheres actually fit.

Problem 16 — Solution

Usable volume = 2,400 cm^3 × 0.74 = 1,776 cm^3

Volume per sphere = usable volume / number of spheres = 1,776 / 310

= ≈ **5.73 cm^3 per sphere**

Common error: dividing the full container volume by the sphere count without applying the packing fraction first, which gives an artificially large sphere volume.

Problem 17 — Solution

Convert container volume: 0.5 m × 0.5 m × 0.5 m = 0.125 m^3

0.125 m^3 × 1,000,000 = 125,000 cm^3

Usable volume = 125,000 × 0.74 = 92,500 cm^3

Number of beads = 92,500 / 1.8 = ≈ **51,389 beads**

Common error: forgetting to convert the container's volume to cubic centimeters before applying the packing fraction, mixing units between the container (meters) and the beads (centimeters).
