Unit 11 · Quantity of Heat

STUDY NOTES

WHAT NEB'S GRADE 11 EXAM ASKS

- **CDC's grid (2077):** Heat and Thermodynamics (Units 9–13 together): 15 of 75 marks
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **CDC's model paper:** a 5-mark short question from this unit: meaning of $L_v = 2.26$ MJ/kg (1), kettle time to boil dry (3), why it takes longer (1)
- **MCQ (1 mark)**
  - low s: heats and cools quickly
  - s of water while boiling (infinite)
  - Newton's law: small difference
  - steam burns worse
  - ice melted by a hot bar
  - mixing three liquids
  - heat capacities from density, s ratios
  - melting point of ice and pressure; regelation
  - ice −10 °C → water 50 °C
  - waterfall heating; ice in water at equilibrium; kettle's heat capacity
- **Short (5 marks, in parts)**
  - meaning of $s = 4200$ J/(kg K); peanuts in a sand bath; fever heat
  - state and explain Newton's law; cooling in equal times
  - heating curve, ice to steam: flat parts, slopes, L_f and L_v
  - heat without temperature rise; hammer → nail
  - boiling under reduced pressure; steam + ice mixture
  - latent heat's role; experiment for L_f of ice; pressure and melting point
  - bullet, silicon chip, coffee in a cup

Key terms

Calorimetry: experimental measurement of heat exchanged; vessel: **calorimeter**.

1 calorie: heat that raises 1 g of pure water by 1 °C (14.5 → 15.5 °C); 1 cal = 4.2 J (4.186 J).

Heat capacity: heat to change a **body's** temperature by 1 K; ms, J/K.

Specific heat capacity: heat to change **1 kg** of a substance by 1 K; J/(kg K).

Newton's law of cooling: rate of heat loss ∝ difference between the body's and the surroundings' temperature.

Principle of calorimetry: in an isolated system, heat lost by hot bodies = heat gained by cold ones.

Latent heat: heat taken in or given out during a change of state at constant temperature.

Specific latent heat of fusion: heat to change 1 kg of solid → liquid at its melting point, no temperature change.

Specific latent heat of vaporization: heat to change 1 kg of liquid → vapor at its boiling point, no temperature change.

Boiling: fast, bubbling change to vapor throughout the liquid at the boiling point.

Evaporation: slow change to vapor from the **surface**, at any temperature.

Regelation: melting of ice under pressure and freezing again when the pressure is removed.

Triple point: the one temperature and pressure where solid, liquid and vapor coexist in equilibrium.

Formulas

$Q = ms\Delta\theta$	m mass (kg), s J/(kg K), $\Delta\theta$ K **Use:** heat equation, same state
$\frac{\Delta\theta_1}{\Delta\theta_2} = \frac{s_2}{s_1}$	equal heat, equal mass **Use:** $\Delta\theta \propto 1/s$
$Q = mL$	L J/kg; ice $L_f = 3.36 \times 10^5$, water $L_v = 2.26 \times 10^6$ **Use:** change of state

$-\frac{dQ}{dt} = K(\theta - \theta_0)$	θ_0 surroundings; K surface area, nature **Use:** Newton's law of cooling
$\ln(\theta - \theta_0) = -\frac{K}{ms}t + C$	straight line, slope $-K/ms$ **Use:** testing the law
$\frac{\Delta\theta}{t} = k(\bar{\theta} - \theta_0)$	$\bar{\theta}$ mean of start and end; $k = K/ms$ **Use:** cooling over a short interval
$s = \frac{(m_w s_w + m_1 s_c)(\theta - \theta_1)}{m_s(\theta_2 - \theta)}$	m_1 calorimeter, m_w water, m_s solid **Use:** method of mixtures
$L_i = \frac{(m_1 s_c + m_w s_w)(\theta_1 - \theta_2)}{m_i} - s_w\theta_2$	m_i ice; θ_1 start, θ_2 end **Use:** latent heat of ice

- energy turned to heat: $mgh = ms\Delta\theta$ (waterfall), $\frac{1}{2}mv^2$ (bullet, hammer) × the fraction that heats it
- heater power P: $Pt = (m_w s_w + C_k)\Delta\theta$ (C_k kettle's heat capacity)

Heat, heat capacity, specific heat

- heat measured only as it passes; work can also raise temperature (shaken thermos, tyre pump)
- **calorimeter**: thin, polished copper with stirrer, insulated box; copper: **low** s (≈ 385 J/(kg K)), good conductor, polished → little radiation
- heat capacity: body (a bucket ≫ a cup); specific heat: substance, depends on state (ice 2100, water 4200)

Substance	s J/(kg K)	Substance	s J/(kg K)
water	4200	ice	2100
aluminium	910	sand	800
iron	470	copper	380
glass	677	mercury	138

High s (water): takes or gives much heat for a small change

- engine coolant; wet cloth for fever
- hot-water radiators; hot-water bag
- land heats and cools faster than sea → sea and land breezes

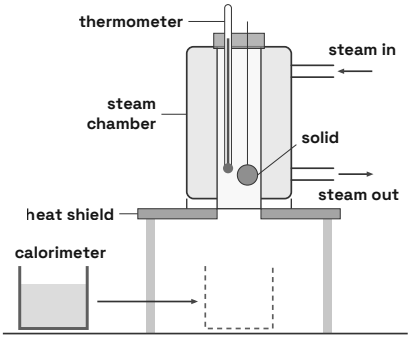
Low s: heats and cools quickly

- mercury in thermometers; copper calorimeter
- cooking oil fries fast (far above 100 °C)
- sand bath for peanuts: sand gets very hot quickly, spreads heat evenly

Newton's law of cooling

- derivation: $dQ = ms\,d\theta \to -ms\frac{d\theta}{dt} = K(\theta - \theta_0) \to$ separate: $\frac{d\theta}{\theta - \theta_0} = -\frac{K}{ms}dt \to$ integrate
- $\theta - \theta_0 = (\theta_1 - \theta_0)e^{-Kt/ms}$: excess falls by the same fraction in equal times
- **holds when**
  - temperature difference **small**
  - heat lost the same way throughout (as by radiation)
  - surroundings at constant temperature
- seen in
  - tea cools fast, then slowly
  - time of death (forensics)
  - tea cools faster in winter
  - hot liquid cools faster than warm
  - animals eat more in winter

Method of mixtures (Regnault)



Solid heated in steam (θ_2), dropped quickly into water in the calorimeter ($\theta_1 \to \theta$).

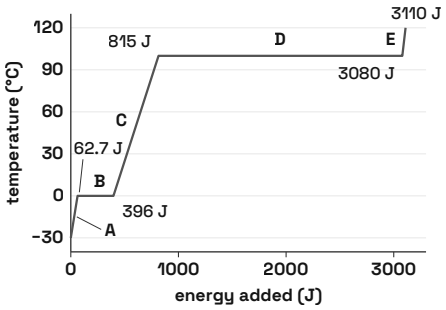
- weigh calorimeter + stirrer m_1; with water m_2; temperature θ_1
- solid in steam till steady θ_2; drop in quickly; stir; highest steady θ
- weigh again m_3: $m_w = m_2 - m_1$, $m_s = m_3 - m_2$
- heat lost $m_s s(\theta_2 - \theta)$ = heat gained $(m_w s_w + m_1 s_c)(\theta - \theta_1)$

Latent heat of ice (mixtures)

- water ≈ 10 °C above room temperature (θ_1); add **dried, melting** ice (at 0 °C)
- stir till melted; lowest steady θ_2; weigh: $m_i = m_3 - m_2$
- ice gains $m_i L_i + m_i s_w \theta_2$ = calorimeter and water lose $(m_1 s_c + m_w s_w)(\theta_1 - \theta_2)$
- starts as far above room temperature as it ends below → heat gained and lost to the room nearly cancel

Change of phase

- pairs: melting ↔ freezing; vaporization ↔ condensation; sublimation ↔ deposition (frost)
- heated: **either** temperature **or** state changes, not both; two phases coexist at the fixed point
- latent heat → particles' **potential energy** (internal latent heat) + work pushing back the air (external)
- $L_v \gg L_f$ (water ≈ 7 ×): particles pulled right apart; steam ≈ 1700 × water's volume
- s while boiling or melting: infinite (heat in, no $\Delta\theta$)
- steam at 100 °C burns worse than water at 100 °C: gives out its L_v as it condenses on the skin



Ice to steam at steady heating: A, C, E slopes (ice, water, steam; steeper = smaller s); B melting at 0 °C, D boiling at 100 °C; D longer than B as $L_v > L_f$.

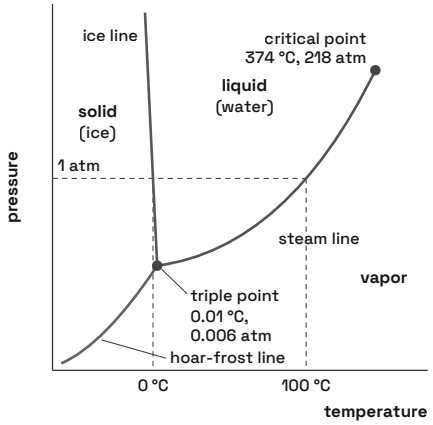
Boiling and evaporation

- boils when **saturated vapor pressure = pressure on the surface**
- pressure ↑ → boiling point ↑ (pressure cooker); height ↑ → ↓
  - Birgunj ≈ 100 °C
  - Namche ≈ 89 °C
  - Kathmandu ≈ 95 °C
  - Everest ≈ 71 °C
- pressure lowered over water → it boils, takes latent heat from itself → temperature **drops**
- evaporation: fastest molecules escape → average KE of the rest ↓ → **cools**
  - sweat; spirit before an injection; drying clothes; water cycle; cold after a bath outdoors

Evaporation	Boiling
surface only	throughout (bubbles)
any temperature	boiling point only
slow, quiet	fast, bubbling
cools the liquid	temperature constant
area, wind, dampness	pressure

Pressure and melting

- **ice** contracts on melting → melting point **falls** with pressure (≈ 0.0075 °C per atm); also cast iron, bismuth
- **wax, lead** expand on melting → melting point **rises**
- regelation: two ice pieces pressed join; wire with weights passes through a block, block stays whole (wire also conducts heat)
- skating: pressure lowers melting point only a fraction of a degree; slipperiness mainly a surface water layer



Phase diagram (P–T) of water: fusion, vaporization and sublimation curves meet at the triple point; fusion curve leans left.

- **vaporization curve**: boiling point vs pressure; ends at the critical point (374 °C, 218 atm)
- **fusion curve**: melting point vs pressure (water: leans left)
- **sublimation curve**: low p, T; dry ice sublimes at −78.5 °C at 1 atm
- triple point: **water 0.01 °C (273.16 K), 0.006 atm** (611.657 Pa, 4.58 mm Hg); CO_2 5.11 atm, −56.6 °C → no liquid CO_2 at 1 atm

COMMON MISTAKES

✗ heat capacity of iron = 470 J/(kg K)
✓ that is **specific** heat capacity; heat capacity = ms (J/K) of a body.

✗ heat added always raises temperature
✓ during a change of state it doesn't (latent heat).

✗ latent heat raises the particles' KE
✓ their **PE**; KE and temperature stay.

✗ Newton's law for any difference
✓ only for a **small** difference.

✗ boiling water and steam burn alike
✓ steam gives out L_v as well.

✗ ice's melting point rises with pressure
✓ it **falls** (ice contracts on melting).

✗ forgetting the calorimeter in heat gained
✓ add $m_1 s_c \Delta\theta$.

✗ ice from −10 °C: only mL
✓ $ms_i \times 10 + mL + ms_w \Delta\theta$.