Unit 12 · Heat

STUDY NOTES

Key terms

Evaporation: liquid → vapor from its **surface**, at any temperature below its boiling point.

Boiling: rapid liquid → vapor, bubbles all through, at a fixed temperature for a given pressure.

Volatile: evaporates quickly (spirit, petrol, acetone, ether).

Thermal expansion: increase in size of a substance when heated.

Linear: increase in length. **Superficial** (areal): in area. **Cubical** (volume): in volume.

Bimetallic strip: two different metals joined face to face along their length.

Latent heat: heat absorbed or given out during a change of state, at constant temperature.

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

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

Heat equation: when a hot and a cold body are in contact in a closed, insulated system, heat lost by the hot body = heat gained by the cold body, until both reach the same temperature.

Formulas

$Q = ms(T_2 - T_1)$	m (kg); s J/(kg °C); temperatures (°C) **Use:** change of temperature
$Q = mL, L = \frac{Q}{m}$	L specific latent heat (J/kg); no °C in it **Use:** change of state
$Q = Pt$	P power (W); t (s) **Use:** heat from a heater or kettle
heat lost = heat gained	ms × fall or rise, plus mL **Use:** mixing

Water	Value
s water / ice	4,200 / 2,100 J/(kg °C)
L fusion of ice	336,000 J/kg
L vaporization	2,260,000 J/kg
L at skin temperature	about 2,400,000 J/kg

Evaporation

- molecules have a **range of speeds**; temperature = **average** KE
- fastest at the surface, moving up, break free
- ∴ average KE of those left falls → **liquid cools**; heat flows in from surroundings → they cool too
- **around us**:
  - sweating
  - dog pants
  - buffalo wallows
  - wet cloth on the forehead
  - *matka* (seeps, evaporates outside)
  - sprinkled courtyard
  - desert cooler
  - shade of a tree (transpiration)
- wet-and-dry-bulb hygrometer: wet bulb lower; bigger difference = drier air (30 °C air, 50% humidity: wet bulb about 22 °C)

Six factors (rate ↑ when)

1. **temperature** ↑: more molecules fast enough (clothes in sun)
2. **surface area** ↑: tea in a saucer; paddy spread thin
3. **humidity** ↓: in humid air almost as many return; 100%: wet things don't dry
4. **wind** ↑: sweeps vapor away, brings dry air
5. **nature**: weaker pull between molecules → faster; volatile > water > mustard oil
6. **air pressure** ↓: easier to escape (mountains, if not too cold)

Evaporation	Boiling
surface only	all through, bubbles
any temperature	boiling point only
slow, quiet	fast, vigorous
cools the liquid	temperature constant while heated
heat from liquid and surroundings	heat supplied from outside
faster: large surface, wind, dry air	doesn't depend on them

- boils at 100 °C at sea level, about 95 °C in Bhaktapur (lower pressure)

Thermal expansion

- **solid**: molecules vibrate harder; **exam line**: larger amplitude, push each other apart, distance increases
- **fuller reason**: force is lopsided: hard to squeeze, easy to pull apart → average spacing moves **outward**
- **liquid**: weaker forces, expands more than a solid
- **gas**: expands most; air about 15 × water, 100 × steel
- 1% each way → about 2% in area, about 3% in volume

- **hole grows too**, like an enlarged photo; tight lid + hot water comes off
- liquid, gas: **cubical only**
- bottle in hot water: level falls first (glass expands first), then rises above the mark
- held rigid: huge force (40 °C rail: about 100 million N/m^2)

Impacts

- rails: gaps, expansion joints; else **sun kink**
- bridges: 1 km grows about 12 mm per 1 °C; rollers, expansion joints
- concrete slabs: gaps with soft filling; wires: sag
- thick glass cracks: inside expands first; borosilicate about ⅓ as much
- shrink fit: hot iron tyre on a wheel, grips as it cools
- dental fillings match the tooth
- tanks and bottles left with space
- tyres harder in the sun
- thermometers

Bimetallic strip

- brass expands about 1½ × iron; heated: bends, **brass outside**; cooled below straight: bends the other way
- thermostat (iron, geyser, rice cooker): at the set temperature bends off its contact, heater off; cools, on again; knob moves the contact
- fire alarm (bends to complete a circuit)
- MCB
- flashers
- dial thermometer

Latent heat

- temperature stops rising while state changes
- melting: heat raises **PE**, not KE: frees molecules from fixed places; water and ice at 0 °C: same KE, water more PE
- boiling: each molecule pulled **completely** away; vapor (about 1,600 × volume) pushes back the air
- ∴ L vaporization ≈ 6.7 × L fusion of water; about 170,000 J/kg pushes back the air (external), the rest internal
- change backward: same energy comes out as heat

Substance	Melts (°C)	L fusion	Boils (°C)	L vapor.
water	0	336,000	100	2,260,000
alcohol	−114	104,000	78	854,000
lead	327	23,000	1,749	866,000
aluminium	660	397,000	2,519	10,500,000
iron	1,538	247,000	2,861	6,090,000

Heating curve, ice → steam

- five parts:
  - ice warms
  - water warms
  - steam warms
  - **flat at 0 °C**
  - **flat at 100 °C**
- ice and steam warm about twice as fast as water (s about half)
- boiling flat about 6.7 × as long as melting

Around us

- steam burn: 10 g gives about 9.5 × boiling water's heat (cooled to 37 °C)
- ice cools better than water at 0 °C
- snow melts slowly (rivers rise steadily)
- lakes freeze slowly
- spray on frosty nights holds buds at about 0 °C; refrigerator: evaporates inside, condenses at the back

Heat equation: the steps

1. list each mass, s, start temperature, L
2. which lose heat, which gain; call final T
3. ms × (larger − smaller) and mL; every term positive
4. lost = gained; solve
5. **check**: T lies between the starting temperatures

- ice in water: first compare the heat water can give cooling to 0 °C with the heat to melt all the ice; too little → ends at **0 °C**, ice left, $m = Q/L$
- calorimeter: copper or aluminium, on a pad, in an insulated container; cools or warms with its contents, so it goes in the equation
- kettle: $L = Pt/m$ comes out high, some heat escapes

COMMON MISTAKES

✗ evaporation produces cold
✓ it takes **heat** away.

✗ hole in a heated plate shrinks
✓ it **grows**.

✗ specific latent heat in J/(kg °C)
✓ **J/kg**.

✗ heat while melting raises KE
✓ raises **PE**; temperature constant.

✗ ice: only mL, forgetting its water warms
✓ $mL + msT$.

✗ T below 0 °C, or outside the range
✓ a mistake; check the ice can all melt.

✗ leaving out the steam's cooling
✓ $mL + ms(100 - T)$.