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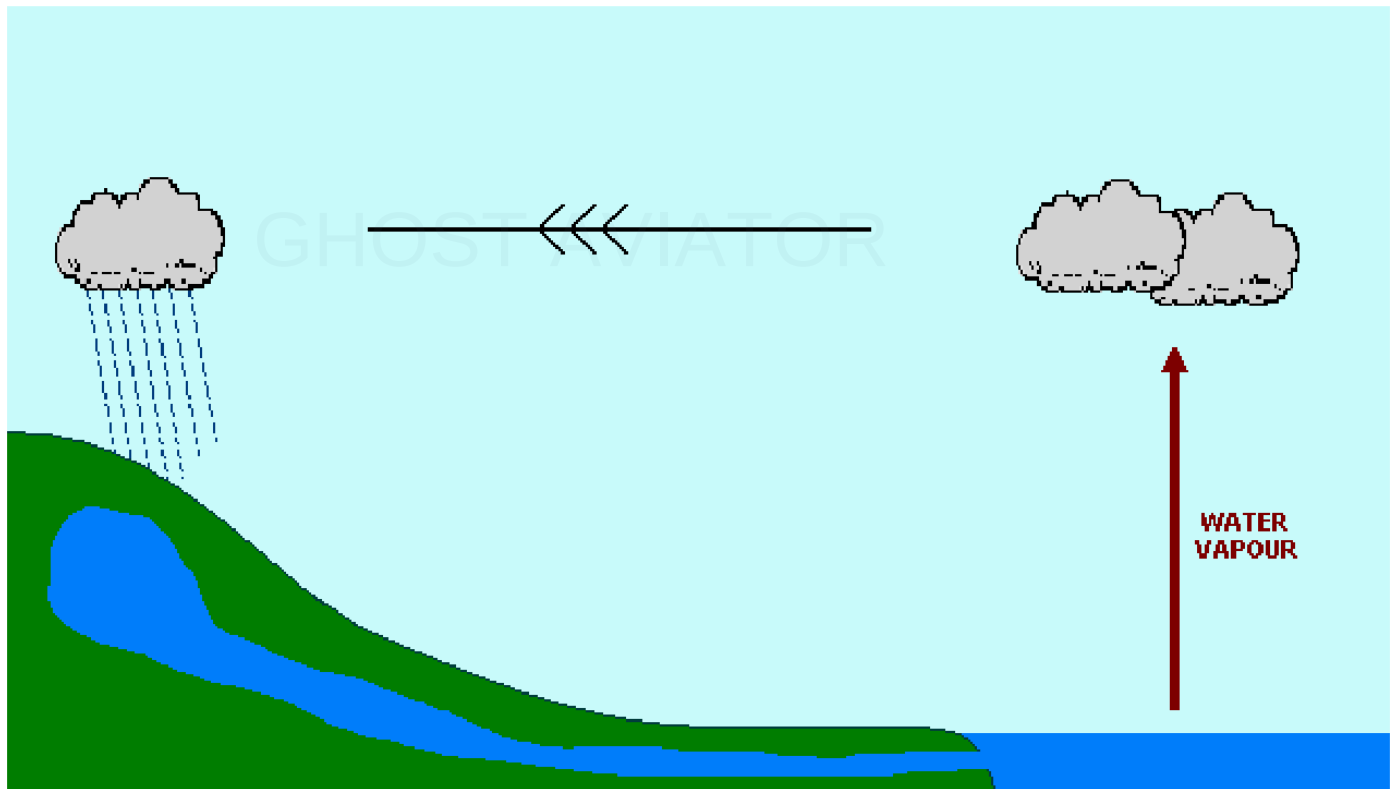
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1. Introduction — Water Vapour & The Water Cycle

Core Concept

Water vapour is always present in the air to a greater or lesser extent, in the troposphere. This water vapour plays a very important role in all the atmospheric processes.



The water cycle

Water evaporates into the air from oceans, lakes, rivers, and vegetation. It ascends and forms clouds which cause precipitation. This is the **water cycle**.

flowchart LR

A[Oceans / Lakes
Rivers / Vegetation] -->|Evaporation| B[Water Vapour
in Atmosphere]

B -->|Ascending air
Cooling| C[Cloud Formation
Condensation]

C -->|Precipitation| D[Rain / Snow / Hail]

D -->|Runoff| A

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⚡ Key Principle

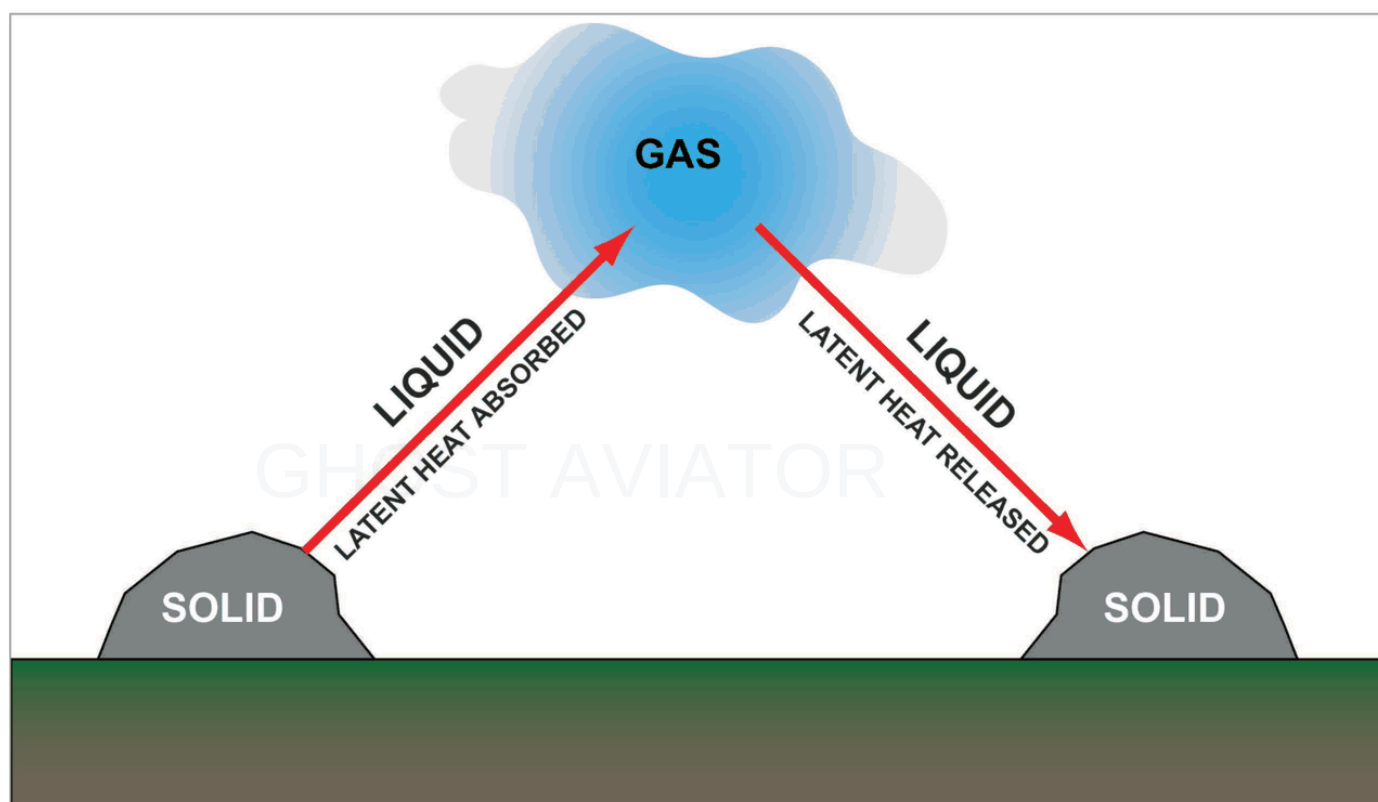
The capacity of dry air to hold water vapour depends largely on **temperature**

(higher temperature = higher capacity) and to some extent on **pressure**

. Higher the temperature, higher the capacity of air to hold water vapour.

2. Three Phases of Water

Phase	State	Examples
Gas	Water Vapour	Invisible moisture in the atmosphere
Liquid	Water	Rain, drizzle, shower, super-cooled water droplets
Solid	Ice	Snow, hail, ice crystals, hoar frost



Change of state and latent heat

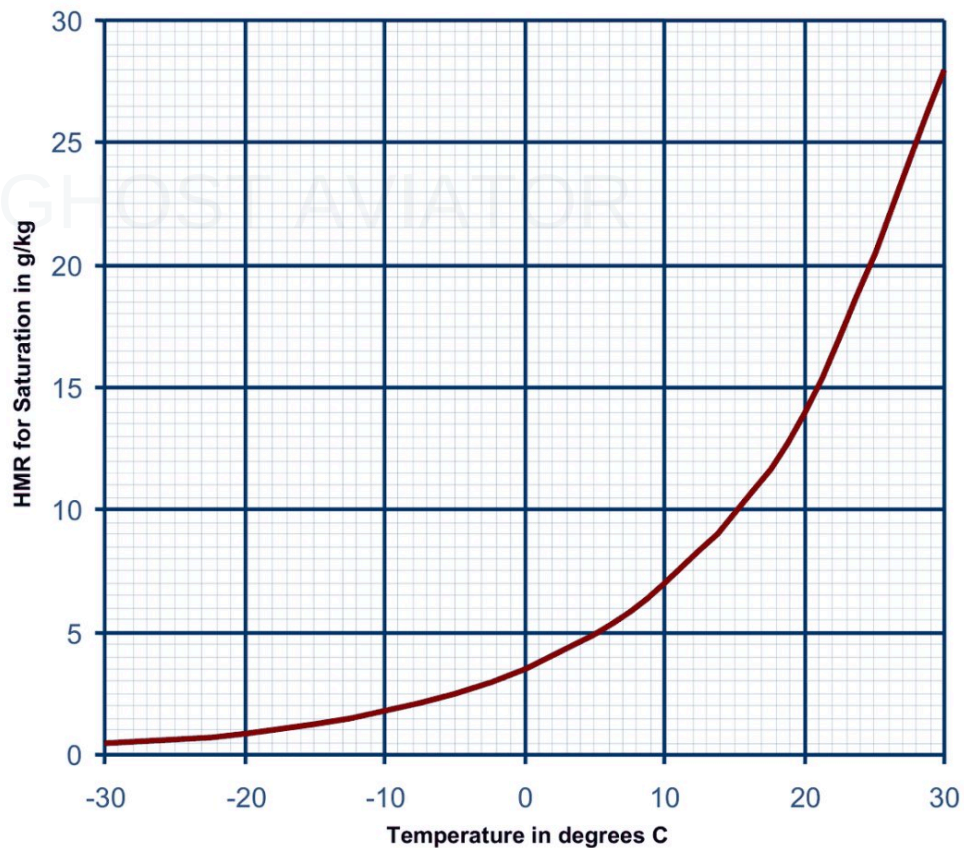
3. Key Humidity Terms & Definitions

Dry Air

Air that contains no water vapour is called

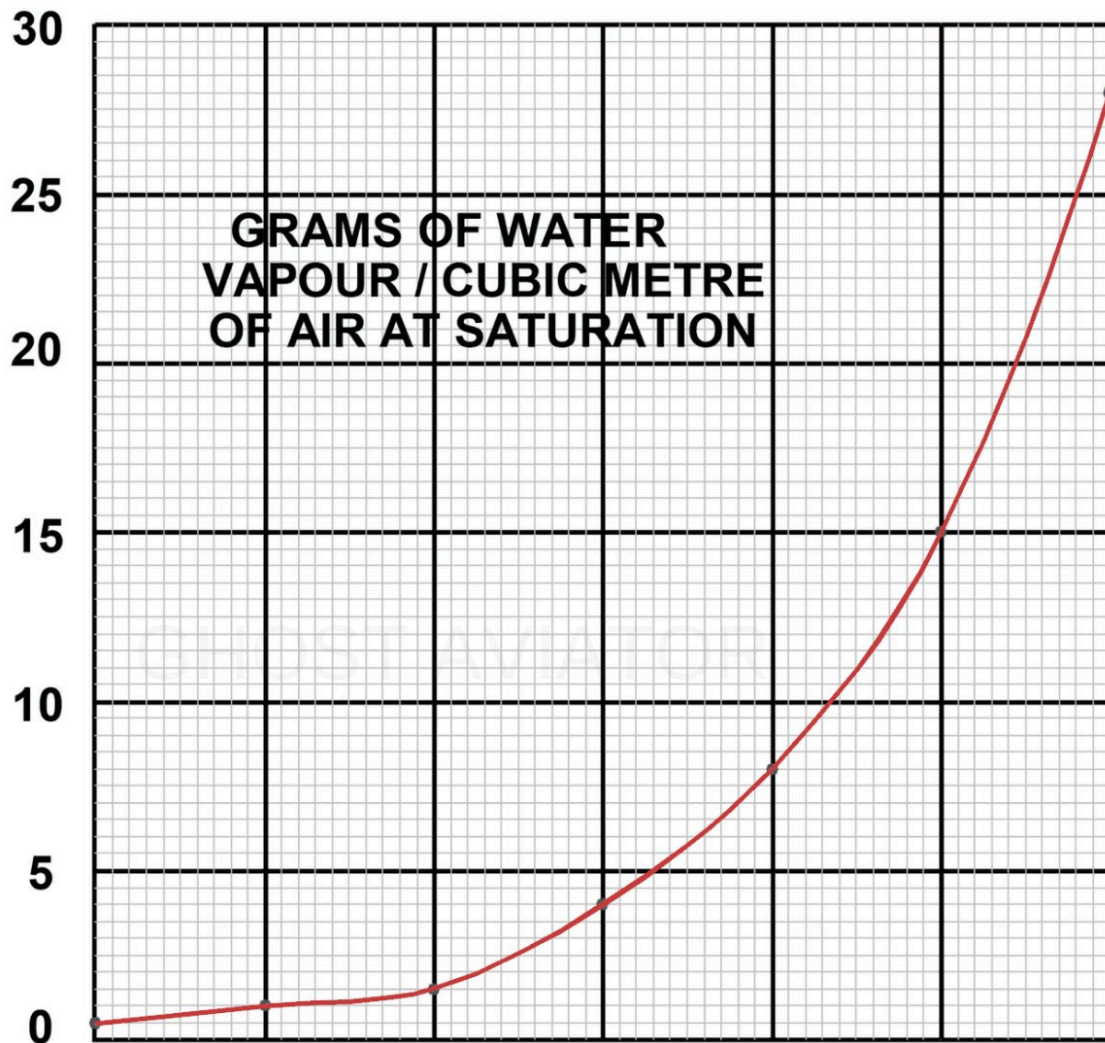
dry air

. Such an air may exist in the upper troposphere or stratosphere.



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Mixing ratio at saturation against temperature



Water vapour the air can hold at saturation

Moist Air

Moist air

is air containing water vapour. It may be saturated or unsaturated. In gas-law calculations,

dry air

means air without water vapour.

Saturated Air

Air is like a sponge which can absorb certain amount of water and no more. When the air holds maximum water vapour, it is called

saturated air

Vapour Pressure (VP)

The partial pressure exerted by the water vapour in the air is called vapour pressure. If p is the total pressure of air and e is the vapour pressure, then

$$(p - e)$$

is the pressure of dry air.

Saturation Vapour Pressure (SVP)

It is the pressure exerted by water vapour when air is saturated.

Absolute Humidity

It is defined as the actual amount of water vapour contained in a given volume of air at a given temperature.

It is expressed in g/m^3 .

Humidity Mixing Ratio (HMR)

It is the mass of water vapour divided by the mass of dry air. It is expressed as g/kg .

HMR for Saturated Air

The maximum mass of water vapour that can be contained in a given mass of dry air at a particular temperature and pressure. Also expressed as g/kg of dry air. The saturation humidity mixing ratio **increases with temperature**.

Term	Definition	Unit	Key Note
Absolute Humidity	Water vapour per unit VOLUME	g/m^3	Changes with T and P
HMR	Water vapour per unit MASS of dry air	g/kg	Constant if no moisture added/removed
Vapour Pressure (VP)	Partial pressure of water vapour	hPa	e in gas equations
SVP	VP when air is saturated	hPa	Increases with temperature

Critical — HMR During Adiabatic Lifting

If there is

no addition or removal of water vapour

, the HMR remains

constant when air is lifted adiabatically

. The mixing ratio is a conservative property during adiabatic processes.

4. Relative Humidity (RH)

Definition

Relative Humidity is defined as the ratio, in percentage, of the

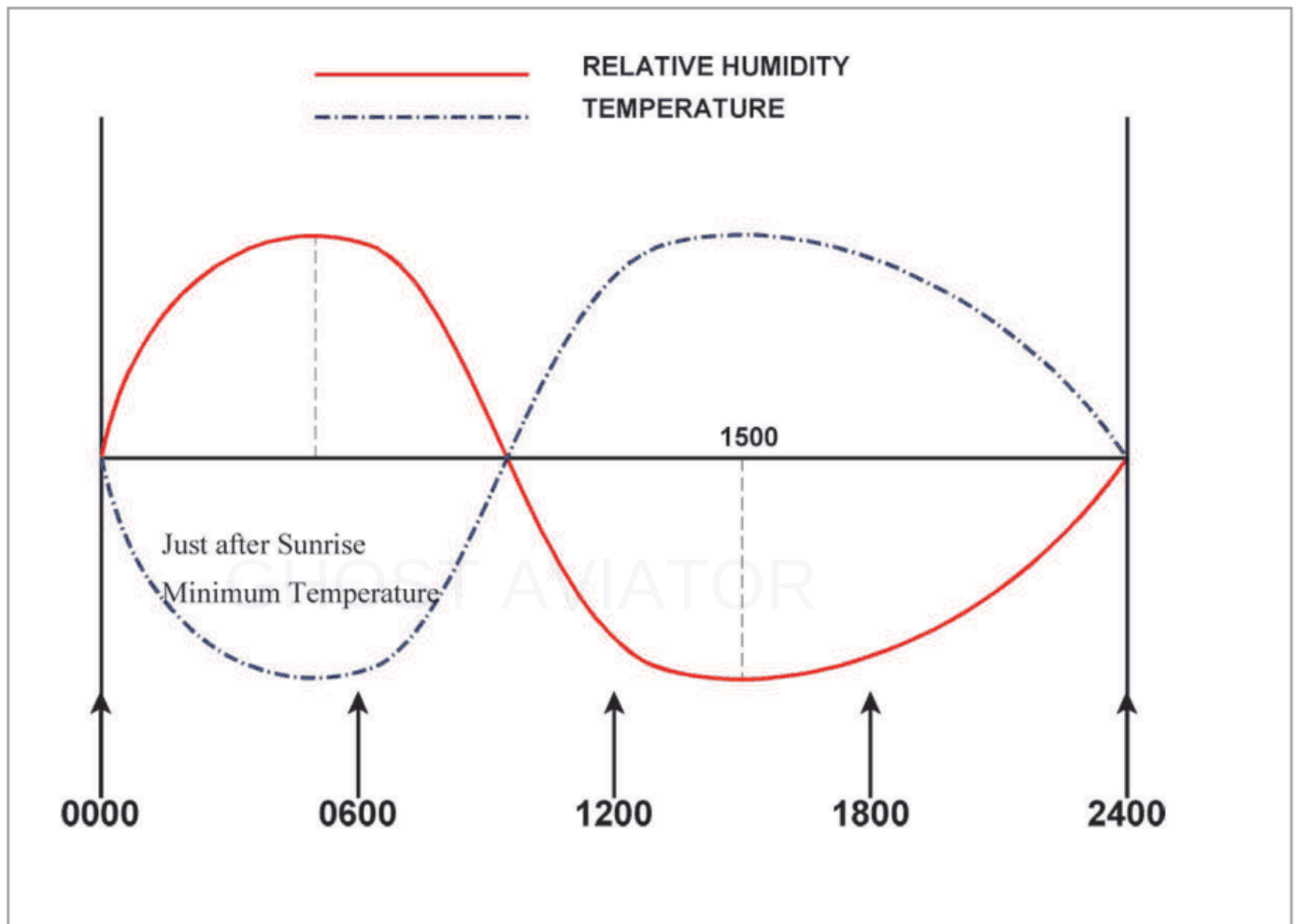
actual water vapour

in the air to the

maximum it can contain

at the same temperature and pressure.

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Diurnal variation of relative humidity

$$RH (\%) = (HMR \times 100) / (HMR \text{ for Saturated Air})$$

OR equivalently:

$$RH (\%) = (VP \text{ of Air} \times 100) / (SVP \text{ of Air})$$

HMR	Humidity Mixing Ratio of actual air
HMR(sat)	HMR for saturated air at same temperature
VP	Actual Vapour Pressure
SVP	Saturation Vapour Pressure at same temperature

⚡ RH Measurement

Humidity is measured by the instruments

Psychrometer

and

Hygrometer

, and is recorded by

Hygrograph

⚠ RH vs Dew Point — Key Distinction

- **RH**
is affected by change in *both* water content AND temperature
- **Dew Point (DP)**
is only affected by change in water content
- By cooling or warming the air,
RH changes but DP does not change
- **DP is higher**
if air contains more water vapour

flowchart TD

```
A[Air Sample] --> B{Change made?}
B -->|Temperature changes\nwater content same| C[RH changes\nDP unchanged]
B -->|Water content changes\ntemperature same| D[Both RH and DP change]
B -->|Air lifted adiabatically\nno water added/removed| E[HMR unchanged\nRH increases as T drops]
```

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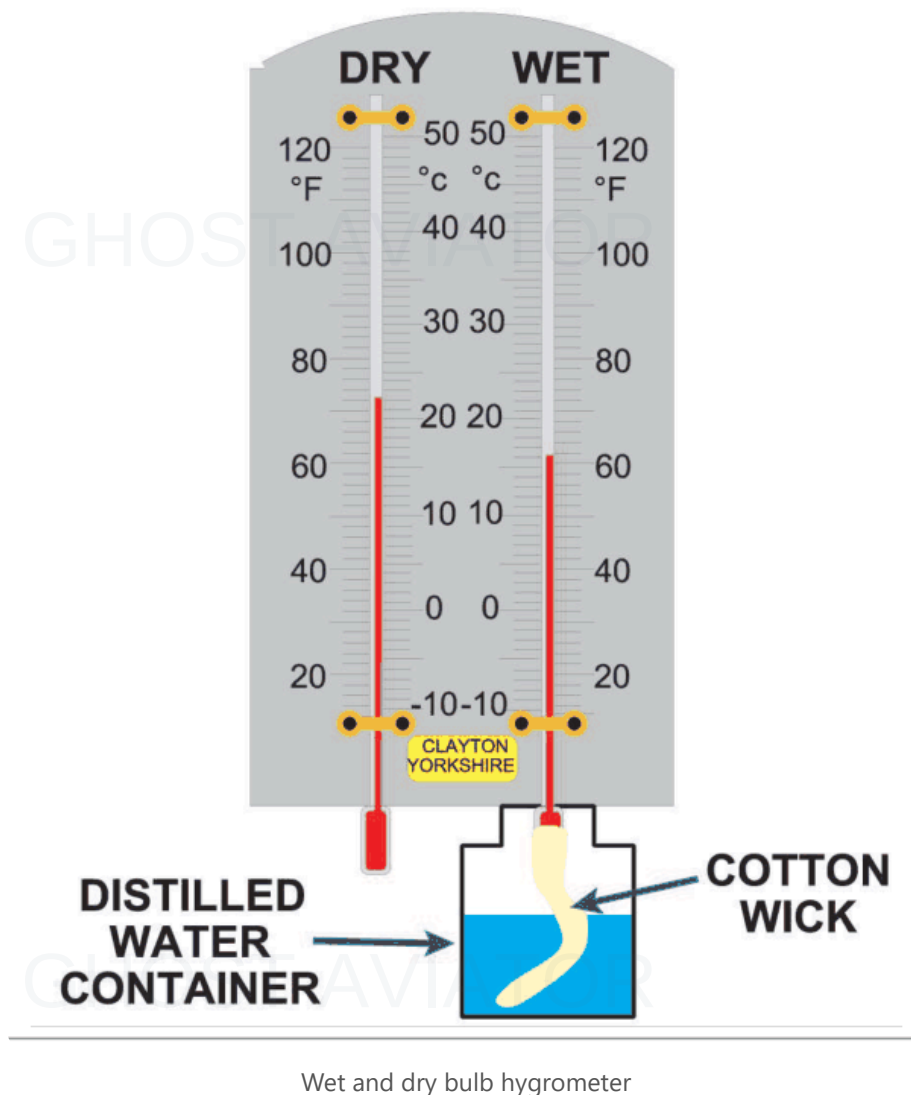
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5. Temperature Parameters — Wet Bulb, Dew Point & Frost Point

Wet Bulb Temperature (T_w)

It is the lowest temperature which air would attain by **evaporating water into it to saturate it**

. Desert coolers work on this principle. The drier the air, the more effective would be the cooling.



Dew Point Temperature (T_{dD} or T_d)

It is the lowest temperature to which air should be cooled at **constant pressure**

to

saturate it with respect to water

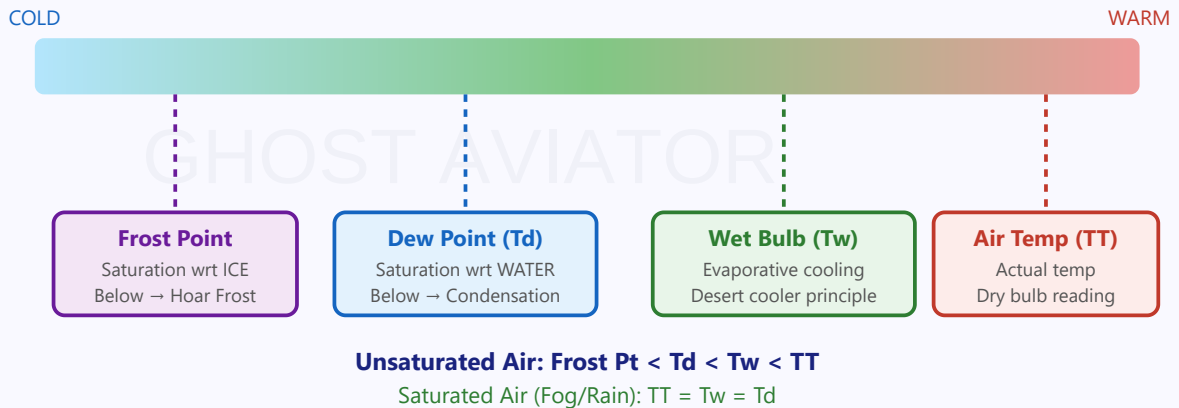
. Cooling below Dew Point (DP) causes condensation.

Frost Point

It is the temperature to which air must be cooled to reach **saturation with respect to ice**

. Cooling below the frost point causes formation of **hoar frost**

Temperature Hierarchy in Unsaturated Air



Temperature	Symbol	Definition	Below This →
Air Temperature	TT	Actual ambient air temperature (dry bulb)	N/A
Wet Bulb Temp	Tw	Lowest T by evaporating water to saturate the air	Not applicable (evaporative limit)
Dew Point	Td / Td	T at which air saturates with respect to water at constant pressure	Condensation (dew, fog)
Frost Point	—	T at which air saturates with respect to ice	Hoar frost formation

Key Relationship — Unsaturated Air

$$TT > Tw > Td \text{ (Unsaturated Air)}$$

$$TT = Tw = Td \text{ (Saturated Air – Fog, During Rain)}$$

When RH = 100%, all three temperatures converge.

6. Cloud Base Calculation

Empirical Cloud Base Formula

The theoretical height of the base of cloud can be determined using surface temperatures by the empirical formula:

$$\text{Cloud Base Height} = (TT - Td) \times 400 \text{ ft}$$

TT	Surface Air Temperature (°C)
Td	Surface Dew Point Temperature (°C)
(TT - Td)	Dew Point Spread or Depression
400 ft	Empirical constant per °C spread

Worked Example — Cloud Base

Given: Surface temperature $TT = 25^{\circ}\text{C}$, Dew Point $Td = 15^{\circ}\text{C}$

DP Spread: $25 - 15 = 10^{\circ}\text{C}$

Cloud Base = $10 \times 400 = 4,000 \text{ ft AGL}$

Note: Smaller the spread between TT and Td, lower the cloud base. When spread = 0, cloud is at surface (fog).

Important

When $TT = Td$ (spread = zero), the cloud base is at the surface — this is **fog**

(or very low stratus). The smaller the dew point depression, the closer the air is to saturation.

Memory Aid

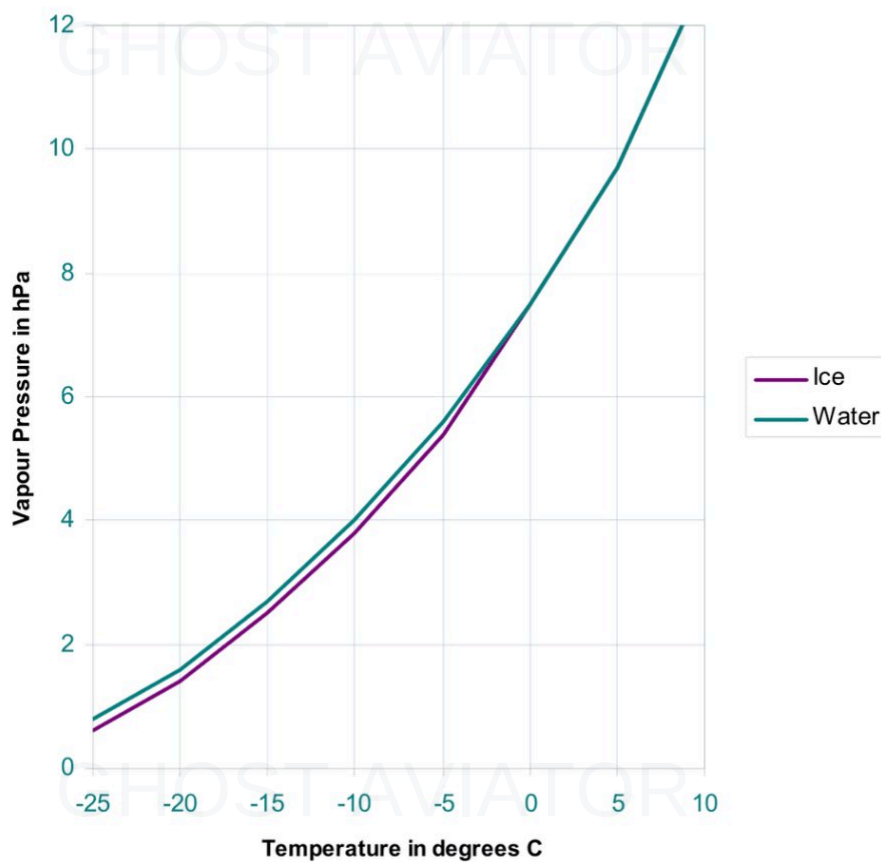
"4-0-0 feet per degree of spread" — if the spread is 5°C , cloud base = 2000 ft. If 10°C , cloud base = 4000 ft. The cooler and moister the air, the lower the cloud base.

7. SVP over Water vs Ice — Sub-Zero Behaviour

Important Sub-Zero Principle

At sub-zero temperatures, water molecules have more energy and a greater degree of freedom than ice. Consequently, the **saturation vapour pressure over water is more than that over ice particles**

SATURATION VAPOUR PRESSURE CURVE



Saturation vapour pressure over water and over ice

⚠️ Bergeron-Findeisen Process — Exam Important

If

water drops and ice particles co-exist

in a cloud:

- SVP over water > SVP over ice at the same temperature
- Water drops evaporate and condense on the ice particles
- Ice particles grow at the expense of water droplets
- This explains

rainfall from clouds which extend above 0°C level

in the atmosphere — mixed-phase clouds produce rain via the Bergeron-Findeisen process

- Both super-cooled water drops and ice crystals can co-exist in this mixed zone

flowchart TD

```
A["Mixed-phase Cloud\n(Water drops + Ice crystals\nat same sub-zero temperature)"] --> B["SVP over Water\nvs SVP over Ice"]
B --> C["SVP(water) > SVP(ice)"]
C --> D["Water drops evaporate"]
D --> E["Water vapour condenses\non ice crystals"]
E --> F["Ice crystals grow\nwater drops shrink"]
F --> G["Ice crystals become heavy\nand fall as precipitation"]
G --> H["Melts below 0°C level\n→ RAIN at surface"]

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⚠️ Super-Cooled Water Droplets — Critical for Aviation Icing

Small water droplets can exist in a

super-cooled

(liquid below 0°C) state:

- In normal clouds: up to **-40°C**
- In Cumulonimbus (CB) clouds: up to **-45°C**
- These super-cooled droplets freeze

on contact

with aircraft surfaces → severe icing hazard

8. Temperature Relationships — Saturated vs Unsaturated Air

✅ Saturated Air (Fog, During Rain)

$$\text{Air Temperature (TT)} = \text{Wet Bulb (Tw)} = \text{Dew Point (Td)}$$

When RH = 100%, the air is saturated and all three temperature readings are identical.

⚡ Unsaturated Air

$$TT > Tw > Td$$

In normal (unsaturated) air, air temperature is highest, wet bulb is intermediate, and dew point is lowest.

Condition	TT vs Tw vs Td	RH	DP Spread
Saturated air (fog, heavy rain)	$TT = Tw = Td$	100%	0°C
Unsaturated air (normal)	$TT > Tw > Td$	< 100%	> 0°C
Very dry air (desert)	$TT \gg Tw > Td$	Very low	Large spread

9. Quick Revision Summary

⚡ Chapter 5 — Quick Revision: Humidity

- Capacity to hold water vapour $\propto$ temperature — higher T = more capacity

- **Absolute Humidity**

: g/m³ (per volume) |

HMR

: g/kg (per mass)

- **RH**

= $(VP/SVP) \times 100\% = (HMR/HMR\text{-sat}) \times 100\%$

- Measured by Psychrometer/Hygrometer; recorded by Hygrograph

- **HMR is constant**

when air lifted adiabatically (no moisture added/removed)

- Saturation HMR increases with temperature

- **Dew Point**

: cooling at constant pressure $\rightarrow$ saturation wrt water $\rightarrow$ condensation

- **Wet Bulb**

: evaporation cools air to saturation; $TT > Tw > Td$ (unsaturated)

- **Frost Point**

: cooling to saturation wrt ice $\rightarrow$ hoar frost below

- Saturated air: $TT = Tw = Td$ ($RH = 100\%$)
- Cooling/warming changes RH but NOT dew point
- DP higher if more water vapour is present
- **Cloud Base = $(TT - Td) \times 400$ ft**
- SVP over water > SVP over ice (sub-zero) $\rightarrow$ Bergeron-Findeisen process
- Super-cooled droplets: up to
-40°C
in clouds, up to
-45°C
in CB

10. Practice Q&A — DGCA Examination Style

Q1. The ratio in % between the amount of water vapour present in the air to the amount of water vapour that it can hold at the same temperature is:

- (a) Humidity (b) Relative humidity (c) Dew point

✓ **Correct Answer: (b) Relative Humidity**

Explanation: Relative Humidity is precisely defined as the ratio (in %) of the actual water vapour content to the maximum water vapour the air can hold at the same temperature and pressure. It is "relative" because it compares actual moisture to maximum possible moisture.

✗ **Distractors:** (a) Humidity — too vague; humidity is the general term for water vapour content. (c) Dew Point — a temperature, not a ratio.

✦ **Instructor's Note:** $RH = (VP/SVP) \times 100 = (HMR/HMR-sat) \times 100$. When $RH = 100\%$, air is saturated. RH depends on BOTH water content AND temperature.

Q2. The temperature to which air be cooled at constant pressure to become saturated is called:

- (a) Wet bulb temperature (b) Dry bulb temperature (c) Dew point (d) Humidity

✓ **Correct Answer: (c) Dew Point**

Explanation: The Dew Point Temperature is defined as the lowest temperature to which air must be cooled at constant pressure to become saturated with respect to water. Below this temperature, condensation occurs.

✗ **Distractors:** (a) Wet Bulb — this is the temperature attained by evaporating water INTO the air, not by cooling it. The process is different. (b) Dry bulb — this is just the ordinary air temperature. (d) Humidity — a measure of moisture content, not a temperature.

✦ **Instructor's Note:** Key distinction — Dew Point is achieved by COOLING at constant pressure. Wet Bulb is achieved by EVAPORATION into the air. Both result in saturation but by different processes.

Q3. Free air temperature, Wet bulb temperature and Dew point temperature are equal when:

- (a) Air temperature is 0°C

- (b) Relative humidity is 100%
- (c) Air temperature is not below 0°C

✔ **Correct Answer: (b) Relative humidity is 100%**

Explanation: When $RH = 100\%$, the air is fully saturated. There is no difference between actual moisture content and maximum possible moisture content, so $TT = Tw = Td$. This condition exists in fog, during heavy rain, or in saturated cloud.

✗ **Distractors:** (a) 0°C is not a condition for equality — it could be 0°C with any RH. (c) Temperature above 0°C has no special significance for this relationship.

🔗 **Instructor's Note:** "Fog = $TT = Tw = Td$ " — when you see fog or are in cloud, assume these three temperatures are equal. This is frequently tested. $RH = 100\%$ is the ONLY condition that makes all three equal.

Q4. On a rainy day compared to sunny day the length of runway required is:

- (a) More
- (b) Less
- (c) Same

✔ Answer: (a) More

A wet runway gives poorer braking action, and standing water adds aquaplaning risk, so both take-off and landing distances increase. This outweighs the small gain from cooler, denser air.

✗ (b) Less and (c) Same ignore the effect of the wet surface.

💡 Wet runway = longer distances. Treat a rainy day as a performance penalty.

Q5. The spread (difference) between Free air temperature and Dew point temperature is when air is saturated:

- (a) Large
- (b) Least
- (c) Same

✔ **Correct Answer: (b) Least (approaches zero)**

Explanation: When air is saturated ($RH = 100\%$), $TT = Td$. The spread between them is zero — the minimum possible. The spread ($TT - Td$) is also called the "dew point depression." Zero spread means the air is at saturation.

✗ **Distractors:** (a) Large — the spread is largest in very dry air (desert conditions). (c) Same — the spread changes constantly with temperature and moisture content.

✦ **Instructor's Note:** DP Spread / DP Depression = $TT - Td$. Spread = 0 → fog/saturation. Spread large → dry air, high cloud bases. Cloud Base = Spread × 400 ft.

Q6. The saturation vapour pressure over water is than the ice:

(a) More (b) Less (c) Same

✓ **Correct Answer: (a) More**

Explanation: At sub-zero temperatures, water molecules in the liquid state have more kinetic energy (greater degree of freedom) than in the solid (ice) state. Therefore, the saturation vapour pressure over liquid water exceeds that over ice at the same temperature. This SVP difference drives the Bergeron-Findeisen process of precipitation formation.

✗ **Distractors:** (b) Less — incorrect; the higher molecular energy of liquid water means higher SVP. (c) Same — there is always a difference at sub-zero temperatures; SVP over water and ice are only equal at exactly 0°C.

✦ **Instructor's Note:** $SVP(\text{water}) > SVP(\text{ice})$ at sub-zero → ice grows, water drops shrink → Bergeron process → rainfall. This is why clouds with both water drops AND ice crystals produce efficient precipitation.

Q7. As the temperature of the air increases, the amount of water vapour required to saturate it:

(a) decreases (b) increases (c) remains same

✓ **Correct Answer: (b) increases**

Explanation: Warmer air has a greater capacity to hold water vapour. The saturation humidity mixing ratio (HMR-sat) and the saturation vapour pressure (SVP) both increase with temperature. This is why warm tropical air can hold much more moisture than cold polar air.

✗ **Distractors:** (a) decreases — opposite is true. (c) remains same — capacity changes significantly with temperature.

✦ **Instructor's Note:** "Warm air = bigger sponge." The SVP curve rises steeply with temperature. This is why tropical air is so humid — warm air can hold more moisture before becoming saturated.

Q8. The actual amount of water vapour contained in a given volume of air at a given temperature is termed as:

(a) Relative Humidity (b) Specific Humidity (c) Absolute Humidity

✓ Answer: (c) Absolute Humidity

Absolute humidity is the actual mass of water vapour in a given volume of air, in g/m^3 .

✗ (a) Relative humidity is a ratio in per cent, not an amount. (b) Specific humidity is the mass of vapour per unit mass of moist air, in g/kg .

💡 Absolute: g per m^3 . Specific/mixing ratio: g per kg . Relative: per cent.

Q9. Humidity Mixing Ratio when air is lifted adiabatically:

(a) Relative Humidity (b) remains constant (c) increases

✓ Answer: (b) remains constant

When unsaturated air is lifted adiabatically no water is added or removed, so the humidity mixing ratio stays constant. What changes is the relative humidity, which rises as the air cools, until it reaches 100% at the condensation level.

✗ (a) Relative humidity is not what the question asks about. (c) The mixing ratio does not increase unless moisture is added.

💡 Lifting unsaturated air: mixing ratio constant, relative humidity increases.

Q10. It is the lowest temperature which air would attain by evaporating water into it to saturate it:

(a) Wet bulb temp (b) Dry bulb temp (c) Dew point

✓ **Correct Answer: (a) Wet Bulb Temperature**

Explanation: Wet Bulb Temperature (T_w) is precisely defined as the lowest temperature which air would attain by evaporating water into it until it is saturated. The evaporative cooling process lowers the temperature to the wet bulb value. Desert coolers work on this same principle — drier the air, more the cooling effect.

✗ **Distractors:** (b) Dry bulb — this is simply the ordinary air temperature measured by an unmodified thermometer. (c) Dew point — cooling the air without adding moisture until it saturates; different process (temperature-lowering vs. moisture-adding).

✂ **Instructor's Note:** Two routes to saturation: (1) ADD MOISTURE → reach Wet Bulb temperature. (2) REMOVE HEAT (cool) → reach Dew Point. Both achieve saturation but by opposite processes. Wet bulb > Dew point in

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11. Master Reference Tables

11.1 All Numerical Values — Chapter 5

Parameter	Value	Context
Absolute Humidity unit	g/m³	Water vapour per unit volume
HMR unit	g/kg	Water vapour per unit mass of air
Cloud base constant	400 ft/°C	Cloud Base = (TT – Td) × 400 ft
Super-cooled droplets (normal clouds)	up to -40°C	Icing hazard
Super-cooled droplets (CB clouds)	up to -45°C	Severe icing in CB
RH at saturation	100%	TT = Tw = Td condition
Dew point spread at saturation	0°C	Fog / in-cloud condition

11.2 Formula Sheet

Formula	Variables	Application
RH (%) = (HMR/HMR-sat) × 100	HMR = actual mixing ratio; HMR-sat = saturation mixing ratio	Relative Humidity calculation
RH (%) = (VP/SVP) × 100	VP = actual vapour pressure; SVP = saturation vapour pressure	Alternative RH formula
Cloud Base = (TT – Td) × 400 ft	TT = air temp, Td = dew point (°C)	Estimating cloud base height AGL
Dry air pressure = p – e	p = total pressure; e = vapour pressure	Pressure partitioning

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11.3 Key Distinctions — Humidity Terms

What Changes?	Effect on RH	Effect on DP	Effect on HMR
Temperature increases only	RH decreases	No change	No change
Temperature decreases only	RH increases	No change	No change
Water content increases	RH increases	DP increases	HMR increases
Air lifted adiabatically	RH increases	No change	No change (constant)

11.5 Mnemonics Quick Reference

All Mnemonics — Chapter 5

- **Absolute = Volume (g/m^3) | HMR = Mass (g/kg)**
- **$\text{RH} = \text{VP}/\text{SVP} \times 100$**
 - "Vapour over Saturation times 100"
- **$\text{TT} > \text{Tw} > \text{Td}$**
 - "Temperature Takes Talent" (decreasing order in unsaturated air)
- **$\text{TT} = \text{Tw} = \text{Td}$**
 - in FOG (Saturated Air, $\text{RH} = 100\%$)
- **Cloud Base = Spread $\times 400$**
 - "(T minus DP) times 400 feet"
- **Cooling $\rightarrow$ RH changes, DP doesn't**
 - "Cool Changes RH, not DP"
- **HMR constant adiabatically**
 - "Mixing Ratio Doesn't Mix when lifted"
- **$\text{SVP}(\text{water}) > \text{SVP}(\text{ice})$**
 - "Water beats Ice" $\rightarrow$ Bergeron process
- **$-40^\circ\text{C} / -45^\circ\text{C}$**
 - Super-cooled droplet limits in clouds/CB
- **Desert Cooler = Wet Bulb principle**
- **Hoar Frost = below Frost Point**
 - (ice saturation temperature)

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