General Meteorology

Lecture 6

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Types of Processes

Distinction between Reversible and Irreversible Processes:

Reversible: One can reverse the process and both the system and the environment will return to its original states

Irreversible: One can reverse the process and return the system to its original state, but the environment will have suffered a permanent change from its original state.

The Concept of Entropy

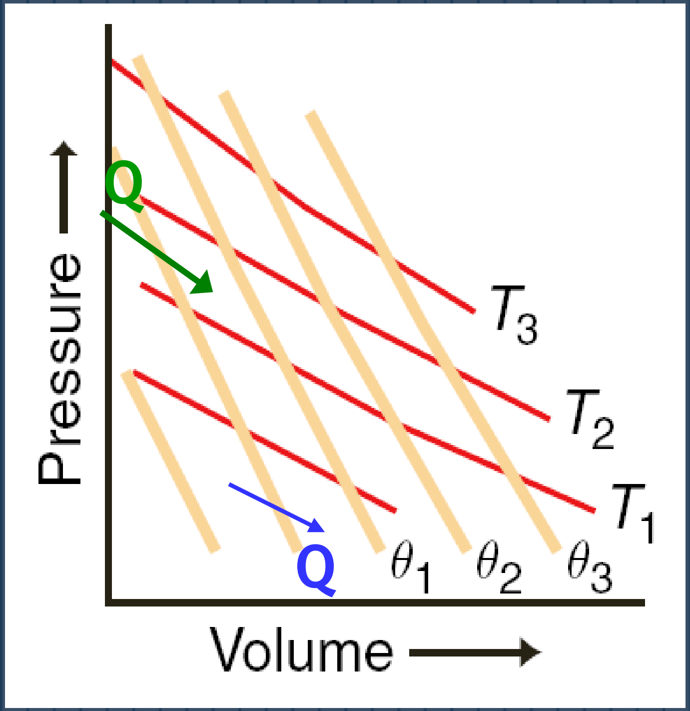
In passing reversibly from one adiabat to another ($\theta_1 \rightarrow \theta_2$) along an isotherm, heat is either absorbed or released

The amount of heat *(Q)* depends on the temperature (*T*) of the isotherm

The ratio *Q*/ *T* is the same no matter which isotherm is chosen in passing from one adiabat to another.

Therefore, the ratio *Q*/ *T* is a measure of the difference between the two adiabats

This difference is called **entropy (S)**.



Note: θ_1, θ_2, θ_3 are **isentropes** or lines of constant entropy

They are also lines of constant potential temperature (i.e. dry adiabats)

The Concept of Entropy

Entropy (S) is a thermodynamic state function (describes the state of system like p, T, and V) and is independent of path

$$dS = \frac{dQ_{rev}}{T}$$

$$ds = \frac{dq_{rev}}{T}$$

mass dependent (S) → units: $J\ K^{-1}$
mass independent (specific entropy) (s) → units: $J\ kg^{-1}\ K^{-1}$

Note: Again, entropy is defined only for reversible processes…

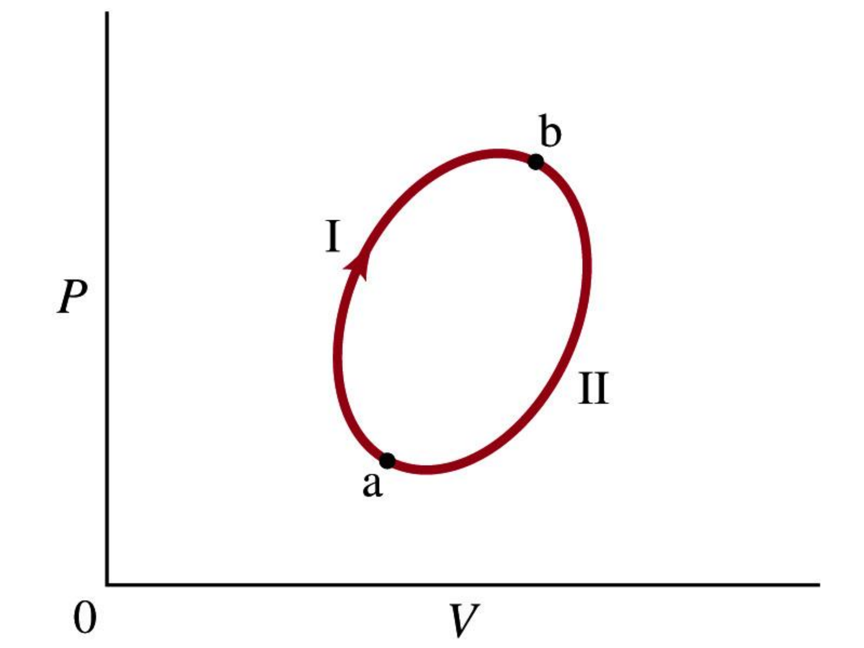
Recall:

- Reversible processes are an idealized concept
- Reversible processes do not occur in nature

Entropy and Reversible Processes

For any **reversible process** (e.g. Carnot cycle):

$$\oint \frac{dQ}{T} = 0$$



$$\int_{I\,a}^{b} \frac{dQ}{T} + \int_{II\,b}^{a} \frac{dQ}{T} = 0$$

$$\int_{I\,a}^{b} \frac{dQ}{T} = -\int_{II\,b}^{a} \frac{dQ}{T} = \int_{II\,a}^{b} \frac{dQ}{T}$$

The entropy of a system in a given state is independent of the path taken to get there, and is thus a **state variable**.

Entropy and Disorder

Entropy is a measure of the disorder of a system.

All real systems tend to disorder - i.e. the entropy of the universe always increases in irreversible processes.

Definition: Entropy is the quantitative measure of disorder in a system. The concept comes out of thermodynamics, which deals with the transfer of heat energy within a system.

Instead of talking about some form of "absolute entropy," physicists generally talk about the change in entropy that takes place in a specific thermodynamic process.

$$\boldsymbol{ds \equiv dq/T}$$

$$dq = c_p dT - \alpha dp$$

$$ds = dq/T = c_p dT/T - (R/p)dp$$

$$\oint dq/T = \oint c_p dT/T - \oint R dp/p$$

But $\oint c_p \, dT/T = 0$

and $\oint R dp/p = 0$

Because T and p are state variables;

Thus: $\boldsymbol{\oint ds = 0}$ Entropy is a state variable.

فرآیند بی دررو خشک

$$ds = \frac{dh}{T}$$

هوای خشک همچون مخلوطی از گازهای ایده آل رفتار می کند که ما برای دمای پتانسیل آن یک فرمول تعیین کردیم.

می توان نشان داد که در خلال فرآیند خشک دمای پتانسیل یک نمونه هوای خشک ثابت می ماند.

$$\theta = T\left(\frac{1000}{p}\right)^{k}$$

$$k = R_d / c_p$$

$$\ln\theta = \ln T + k\ln 1000 - k\ln p$$

$$d(\ln\theta) = d(\ln T) - k d(\ln p)$$

$$c_p d(\ln \theta) = c_p d(\ln T) - R_d d(\ln p)$$

$$k = R_d / c_p$$

$$c_p d(\ln \theta) = c_p \frac{dT}{T} - R_d \frac{dp}{p}$$

$$ds = c_p d(\ln\theta)$$

$$ds = 0 \ \text{ a dry adiabatic process}$$

$$d(\ln\theta) = \frac{d\theta}{\theta} = 0$$

$$d\theta = 0 \Rightarrow \theta = \text{costant}$$

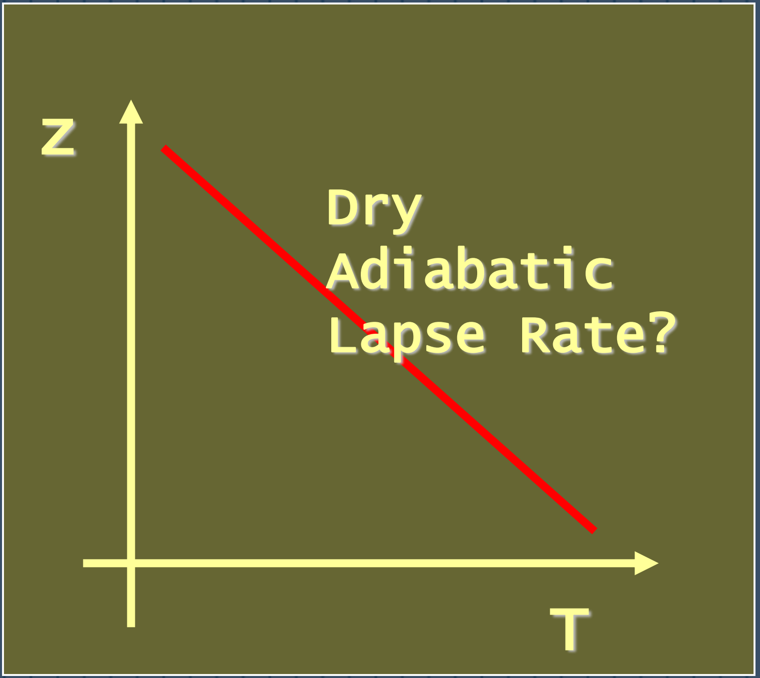
Dry Adiabatic Lapse Rate

How does Temperature change with Height for a Rising Thermal?

Potential temperature is a function of pressure and temperature: θ (p,T)
We know the relationship between pressure (p) and altitude (z):

$$\frac{dp}{dz} = -\rho g$$

Hydrostatic Relation
(more on this later)



relationship between temperature and height when potential temperature is conserved (dry adiabatic lapse rate)

$$c_p dT = \alpha dp$$

Adiabatic Form of the First Law

Dry Adiabatic Lapse Rate

How does Temperature change with Height for a Rising Thermal?

$$c_p \, dT = \alpha \, dp$$

Substitute for "a" using the Ideal Gas Lawand rearrange:

$$\frac{dT}{T} = \frac{R_d}{c_p} \frac{dp}{p}$$

Divide each side by "dz":

$$\frac{1}{T} \frac{dT}{dz} = \frac{R_d}{c_p} \frac{1}{p} \frac{dp}{dz}$$

Substitute for "dp/dz" using the hydrostatic relation and re-arrange:

$$\frac{dp}{dz} = -\rho g$$

$$\frac{dT}{dz} = -\frac{\rho T R_d}{p} \frac{g}{c_p}$$

$$\frac{dT}{dz} = -\frac{\rho TR_d}{p}\frac{g}{c_p} \quad \longleftarrow \quad p = \rho R_d T$$

$$\frac{dT}{dz} = -\frac{g}{c_p}$$

We have arrived at the **Dry Adiabatic Lapse Rate (Γ_d):**

$$\Gamma_d = \frac{dT}{dz} = -\frac{g}{c_p} = -9.8\,°C/km$$

Example: Temperature Change within a Rising Thermal

A parcel originating at the surface (z = 0 m, T = 25°C) rises to the top of the mixed boundary layer (z = 800 m). What is the parcel's new air temperature?

$$\frac{dT}{dz} = -9.8\,°C/km$$

$$T_{final} = (-9.8\,°C/km)\,dz + T_{initial}$$

$$T_{final} = -9.8 * 0.8 + 25$$

$$T_{final} = 17.2\ °C$$