THE UNIVERSITY OF UTAH

# ATMOS 5130

## Lecture 9

- Enthalpy
- Conservation Property
- The Second Law and Its Consequences
    - Entropy

# CLASS Presentation

- Form group of 2 students
- Present ~20 minute presentation (~ 10 minute each person)
- Focus on topics found within “In Practice” section of your textbook.
- Your research should go beyond the textbook.
- Be Creative!   Props

# Examples of material to present

- Hygrometer
- Wind Chill
- Radiosonde
- Skew-T diagram
- Psychrometer
- Heat Index
- Aneroid Barometer
- Altimeter
- Subsidence inversion

# Suggestions for effective display

- **Keep it simple!** Fancy designs or color shifts make important material hard to read. Less is more.
- Use at least a 24-point font so everyone in the room can read your material.
- Try to limit the material to eight lines per slide, and keep the number of words to a minimum. **Keep it simple**.
- Limit the tables to four rows/columns for readability. Sacrifice content for legibility. Large tables can be displayed more effectively as a graph.
- Use easily read fonts.
- Don't fill up the slide - the peripheral material may not make it onto the display screen.
- **Identify the journal when you give references.**
- Finally, always preview your presentation. You will look foolish if symbols that looked OK in a WORD document didn't translate into anything readable in POWERPOINT.

# First Law of Thermodynamics

- Special Case of the Law of Conservation of Energy
- Energy stored by the parcel is its **internal energ**y
  - Pressure volume work done by the system = reduction in internal energy + heat supplied by the environment
  - Pressure volume work done on the system = increase in internal energy + heat transferred tothe environment

Review

$$\delta w = -du + \delta q$$

Where $\delta w$ = increment of **work** (per unit mass
$du$ = change in the **internal energy** (per unit mass)
$\delta q$ = increment of **heat energy** (per unit mass)

Recall: $\delta w \equiv p\, d\alpha$

$$\delta q = -du + p\, d\alpha$$

# First Law of Thermodynamics

Review

$$\delta q = c_v\, dT + p\, d\alpha$$

$$\delta q = c_p\, dT - \alpha\, dp$$

# Enthalpy – Sensible Heat

- Accounts for both the gain in internal energy of the parcel and the mechanical work done in displacing the surrounding air as it expands

# Enthalpy – Sensible Heat

Specific Enthalpy – intensive units

$$h \equiv u + p\alpha$$

Internal energy

Mechanical work

$$dh \equiv du + d(p\alpha) = du + \alpha dp + p d\alpha$$

$$\delta q = du + p\, d\alpha$$

Substitute in 1st law of Thermo

$dh - \alpha dp = du + p d\alpha$

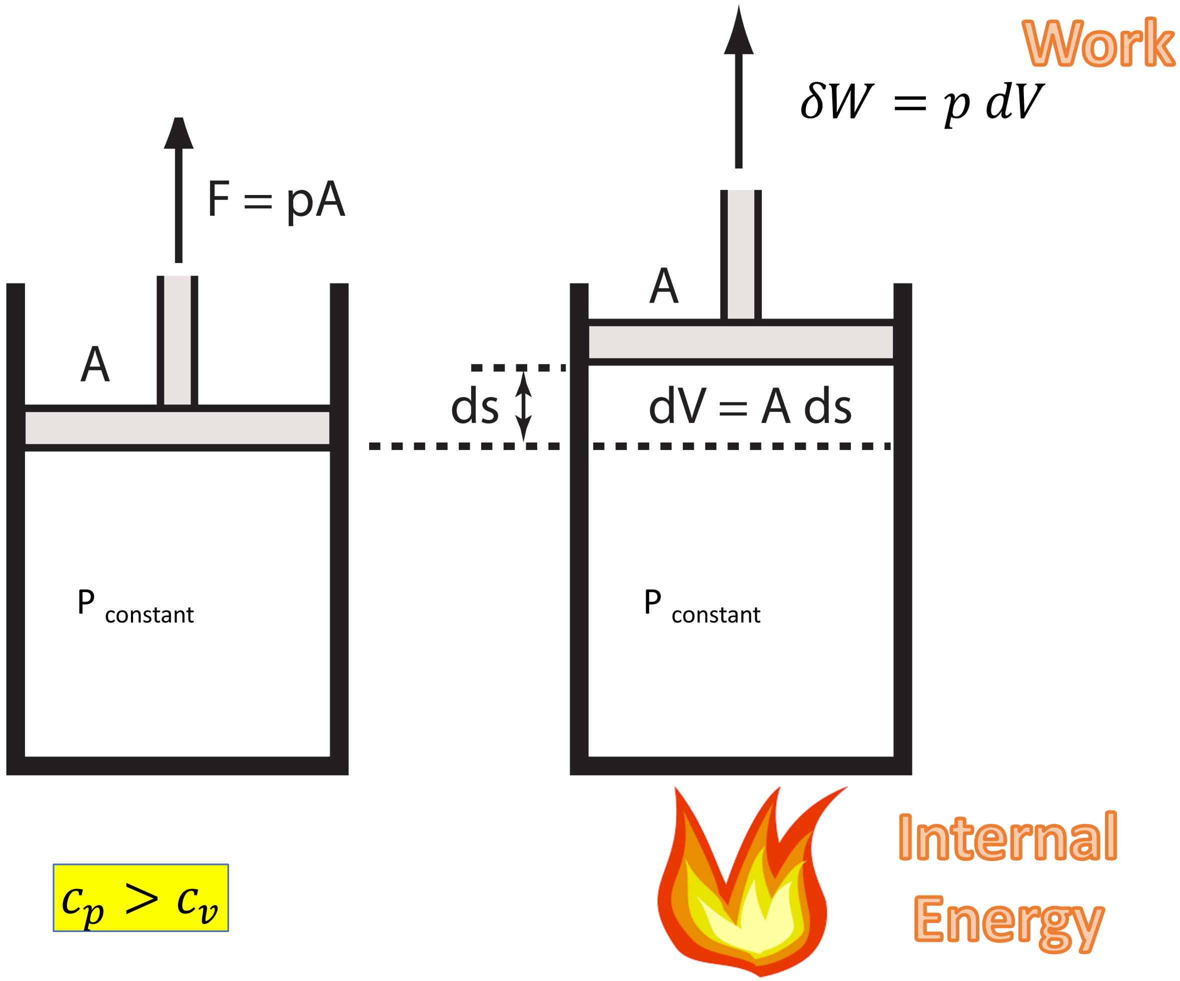
$$\delta q = dh \ - \alpha\, dp$$

$$\delta q = c_p dT \ - \alpha\, dp$$

Compare to 1st law form

$$\boxed{dh \equiv c_p dT}$$

Heat Capacity at Constant Pressure = Isobaric case




$c_p > c_v$

# Special Cases of the First Law

$$\delta q = c_v\, dT + p\, d\alpha$$
$$\delta q = c_p\, dT - \alpha\, dp$$

Review

<u>Isobaric Process</u>: (dp = 0)

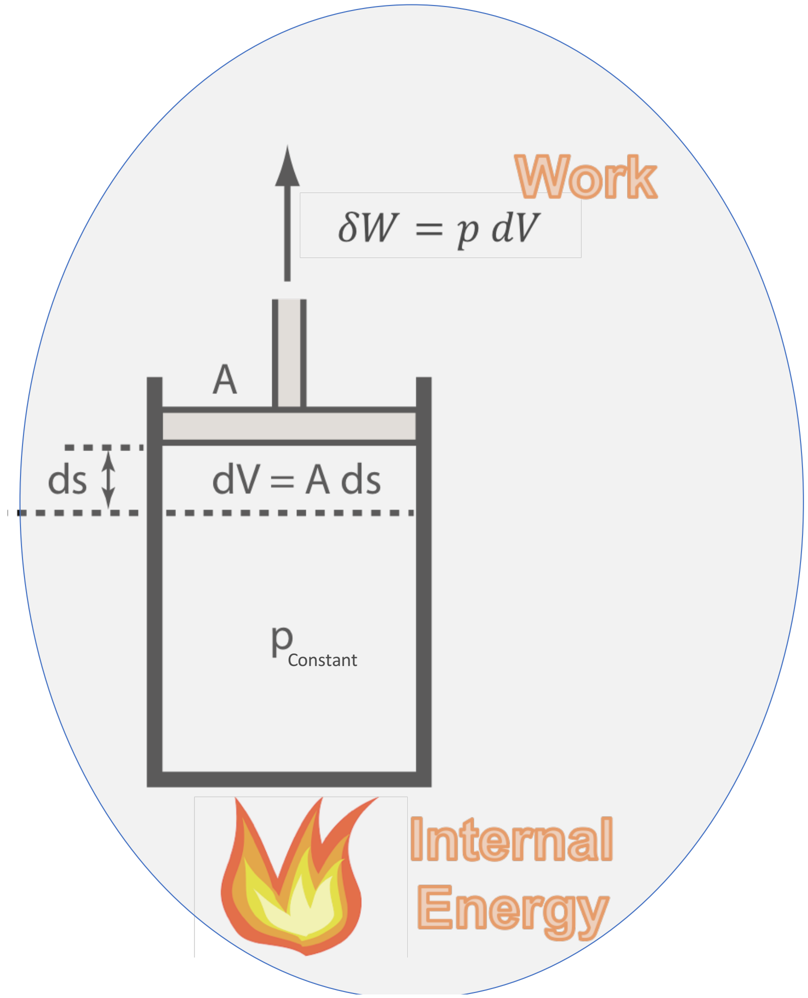
$$\delta q = c_p\, dT$$

Isothermal Process

Isochoric Process

Adiabatic Process

# Enthalpy – Sensible Heat




$$\boxed{dh \equiv c_p dT}$$

Gain in heat at constant pressure = Gain in Enthalpy

# Enthalpy – Sensible Heat

- Accounts for both the gain in internal energy of the parcel and the mechanical work done in displacing the surrounding air as it expands

Specific Enthalpy – intensive units

$$h \equiv u + p\alpha$$

Internal energy

Mechanical work: "work required to make room for the parcel by displacing the surrounding atmophere.

# Enthalpy – Sensible Heat

Specific Enthalpy – intensive units

$$h \equiv u + p\alpha$$

Internal energy

Mechanical work

$$dh \equiv du + d(p\alpha) = du + \alpha dp + p d\alpha$$

$$\delta q = du + p\, d\alpha$$

Substitute in 1st law of Thermo

$dh - \alpha dp = du + p d\alpha$

$$\boxed{\delta q = dh - \alpha\, dp}$$

New form of 1st law in terms of enthalpy

# Dry Static Energy Conservation

$$\delta q = dh \; - \alpha \, dp$$

Substitute in the Hydrostatic relationship

$$dp = -\rho g \, dz$$

Assumes the environmental temp ~ temp of parcel

$$\delta q = dh \; - \alpha \, (-\rho g \, dz)$$

Recall $\alpha = \frac{1}{\rho}$ and $d\phi = g \, dz$

$$\delta q = dh \; - \alpha \, (-\rho g \, dz)$$

$$\delta q = dh + d\phi = d(h + \phi)$$

$$h + \phi$$

Dry Static Energy

Conserved in dry adiabatic situation

# Real World – Generalization to an irreversible process

What happens when the environmental temperature is not equal to parcel temperature?

- Not in Equilibrium – Positive or Negative Buoyancy
- Forces acting on the parcel as it is displaced, gains/loses kinetic energy (i.e. it accelerates).

$$\delta q = dh + d\phi + e_k$$

- Dissipates kinetic energy – stops accelerating
- That kinetic energy must heat the parcel or environment. How much to parcel and how much to environment? We don't know.

$$\delta q \geq dh + d\phi$$

# First Law applied to cyclic process

Recall:

$$q_{net} = w_{net} = \oint \delta q = \oint c_v dT + \oint p \, d\alpha \neq 0$$

Thus, heat is not a state variable!

# First Law applied to cyclic process

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$$q_{net} = w_{net} = \oint \delta q = \oint c_v dT + \oint p\, d\alpha \neq 0$$

Thus, heat is not a state variable!

# Specific Entropy

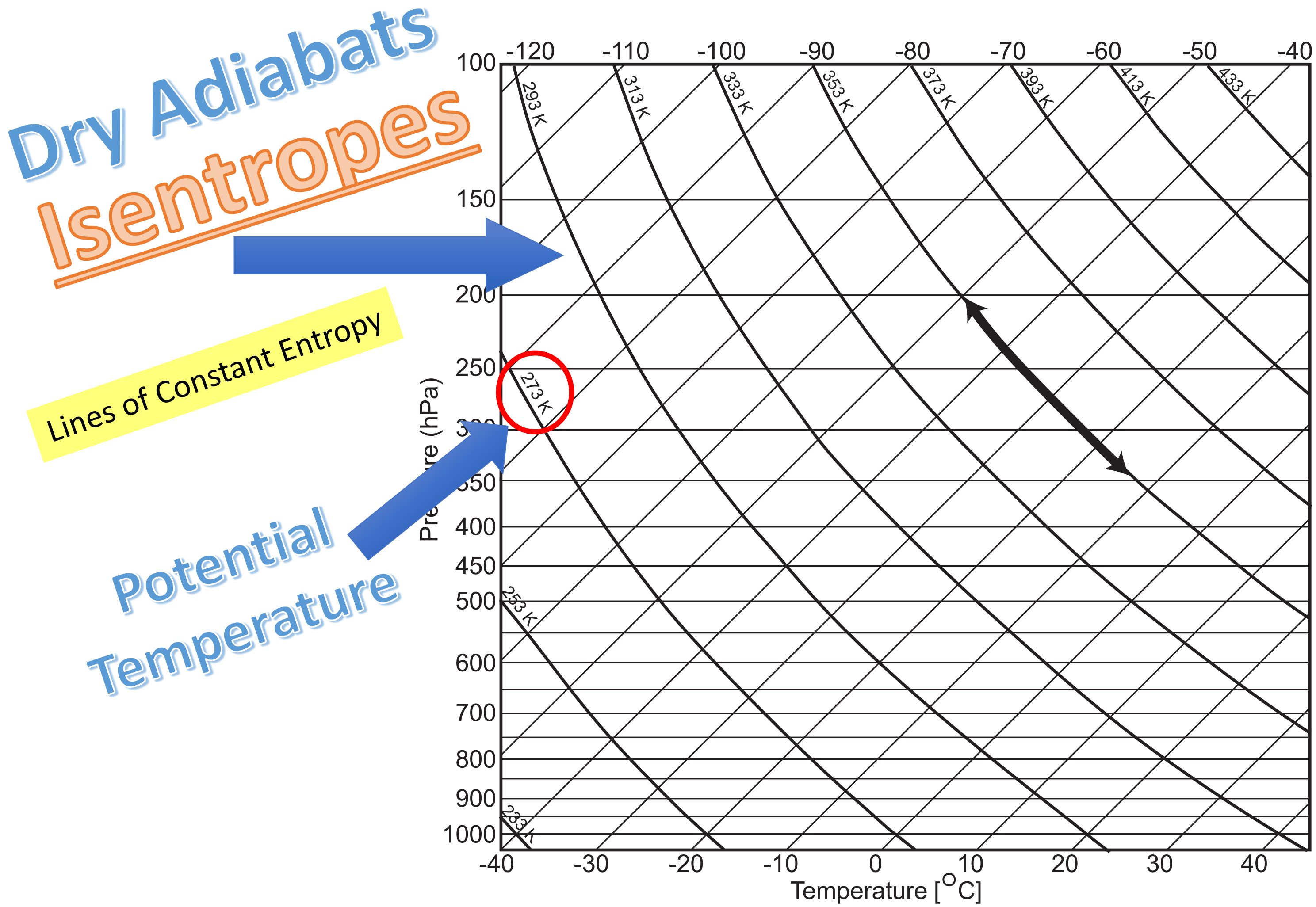
NEW STATE VARIABLE

$$\oint \frac{1}{T}\delta q = \oint \frac{1}{T} c_v dT + \oint \frac{1}{T} p\, d\alpha$$

$$\oint \frac{1}{T}\delta q = c_v \oint \frac{dT}{T} + R \oint \frac{1}{\alpha}\, d\alpha$$

$$\boxed{\oint \frac{1}{T}\delta q = 0 \equiv ds}$$

Now all in state variables



Dry Adiabats
Isentropes
Lines of Constant Entropy
Potential Temperature
-120 -110 -100 -90 -80 -70 -60 -50 -40
100
150
200
250
400
450
500
600
700
800
900
1000
(hPa)
293 K
313 K
333 K
353 K
373 K
393 K
413 K
433 K
273 K
253 K
233 K
-40 -30 -20 -10 0 10 20 30 40
Temperature [$^{O}$C]


Fig. 5.3

$$\delta q = c_v\, dT + p\, d\alpha$$
$$\delta q = c_p\, dT - \alpha\, dp$$

First Law of Thermodynamics
in term of Entropy

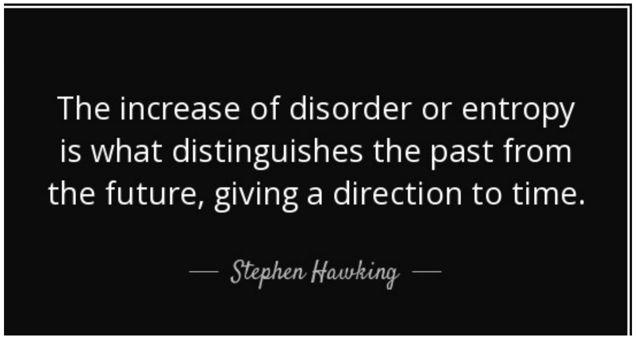
$$ds = c_v\, d\ln T + R\, d\ln \alpha$$
$$ds = c_p\, d\ln T + R\, d\ln \mathrm{p}$$

Entropy = Energy dispersal

- Unconstrained energy spontaneously tends to disperse
- For example, energy spontaneously flows from hot to cold

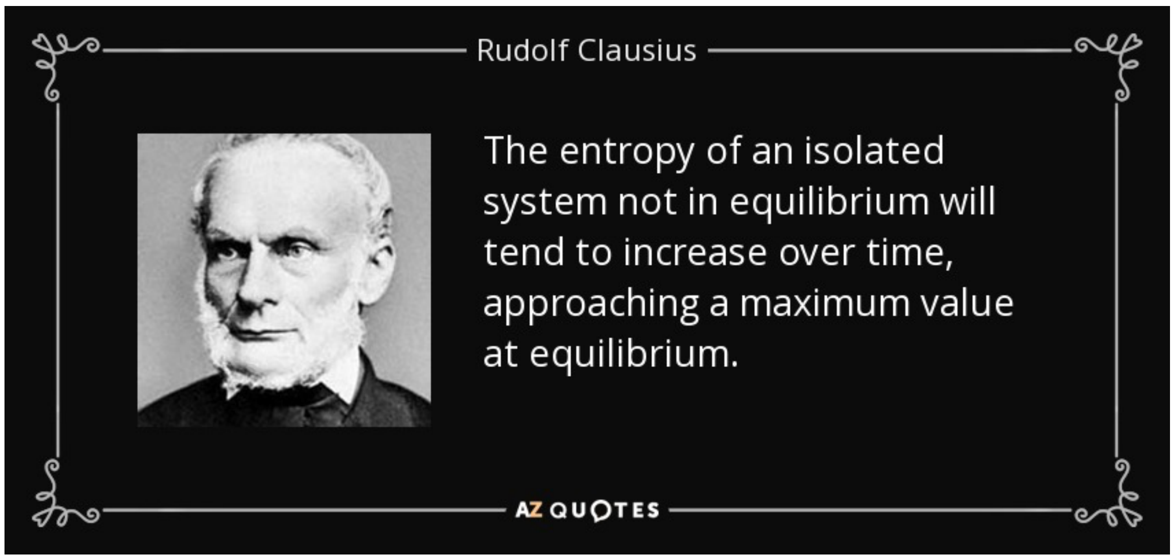
# Second Law of Thermodynamics

- Within any isolated system that is not at equilibrium, the net effect of any active process is to always to increase the total entropy of the system.
- A state of equilibrium is reached when the totally entropy of the system has achieved its maximum possible value. At this point, no further evolution of system state variables is possible



# Second Law of Thermodynamics

- Thermal equilibrium in a two body system is reached when both bodies have the same temperature



# In Class problem

Calculate the change in air pressure if the specific entropy decreases by 0.05 J $g^{-1}K^{-1}$ and the air temperature decreases by 5%.

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Calculate the change in air pressure if the specific entropy decreases by 0.05 J $g^{-1}K^{-1}$ and the air temperature decreases by 5%.

$$ds = c_p \, d\ln T + R \, d\ln \mathrm{p}$$

$$\ln\frac{p_f}{p_i} = \frac{c_p}{R}\ln\left(\frac{0.95T_i}{Ti}\right) - \frac{ds}{R}$$

$$\ln\frac{p_f}{p_i} = \frac{1005}{287}\ln\left(\frac{0.95T_i}{Ti}\right) - \frac{-50}{287}$$

$$p_f = 0.994\, p_i$$

Pressure will decrease by a small amount of ~ 0.6%