Thermal & Statistical Physics

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PHYS 343

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Statistical Physics

Part II

Lecture 1

Heat and work

Heat and work

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Heat and work

- *Thermodynamic processes and entropy*
- *Thermodynamic cycles*
- *Extracting work from heat*

  How do we define engine efficiency?

  Carnot cycle --- best possible

References for this Lecture:
Elements Ch 2

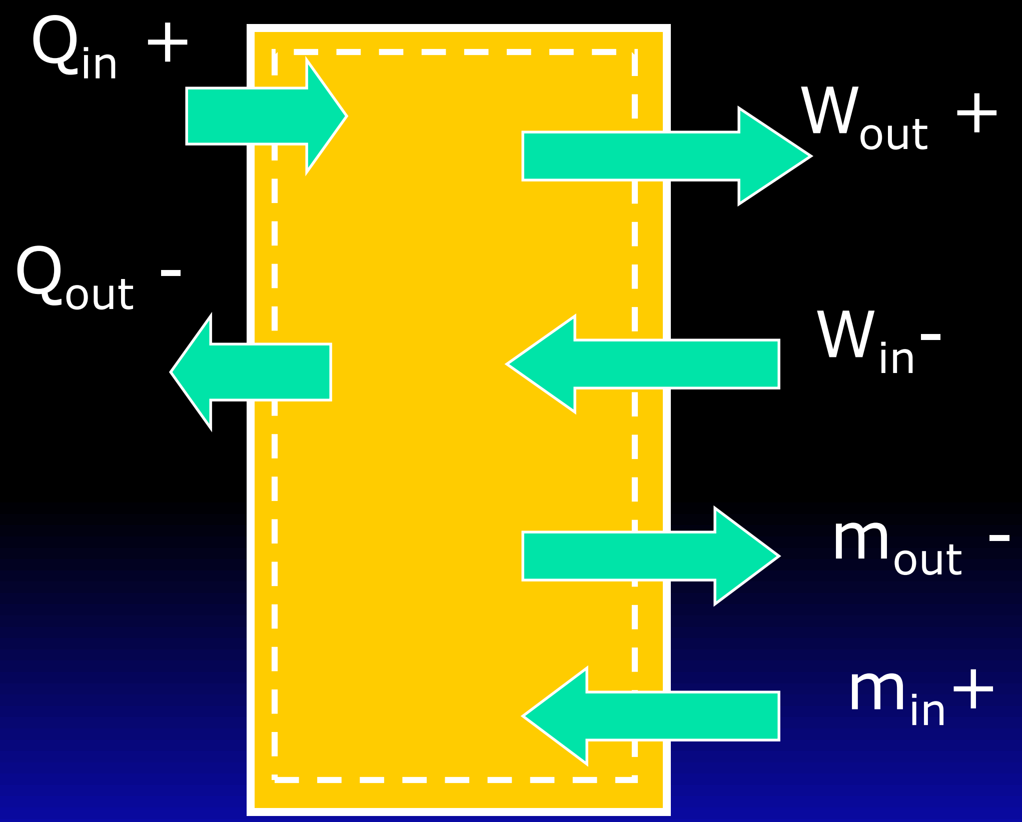
- ***Outline:***
  - Conventions for heat and work
  - Work
  - Heat
- :***Important points***
  - How to determine the direction of heat and work flow
  - Integral and specific case equations for heat and work
  - How to compute work from property paths

Energy Transfer

- **Open system or control volume--** energy can be added to or taken away from the system by heat transfer, work interactions, or with the mass that flows in or out.

- **Closed systems--**energy transfer is only by heat and work interactions, because by definition no mass goes in or out.

Signs for heat, work and mass transfer



Sign convention

Q_{in} is positive

Q_{out} is negative

W_{in} is negative

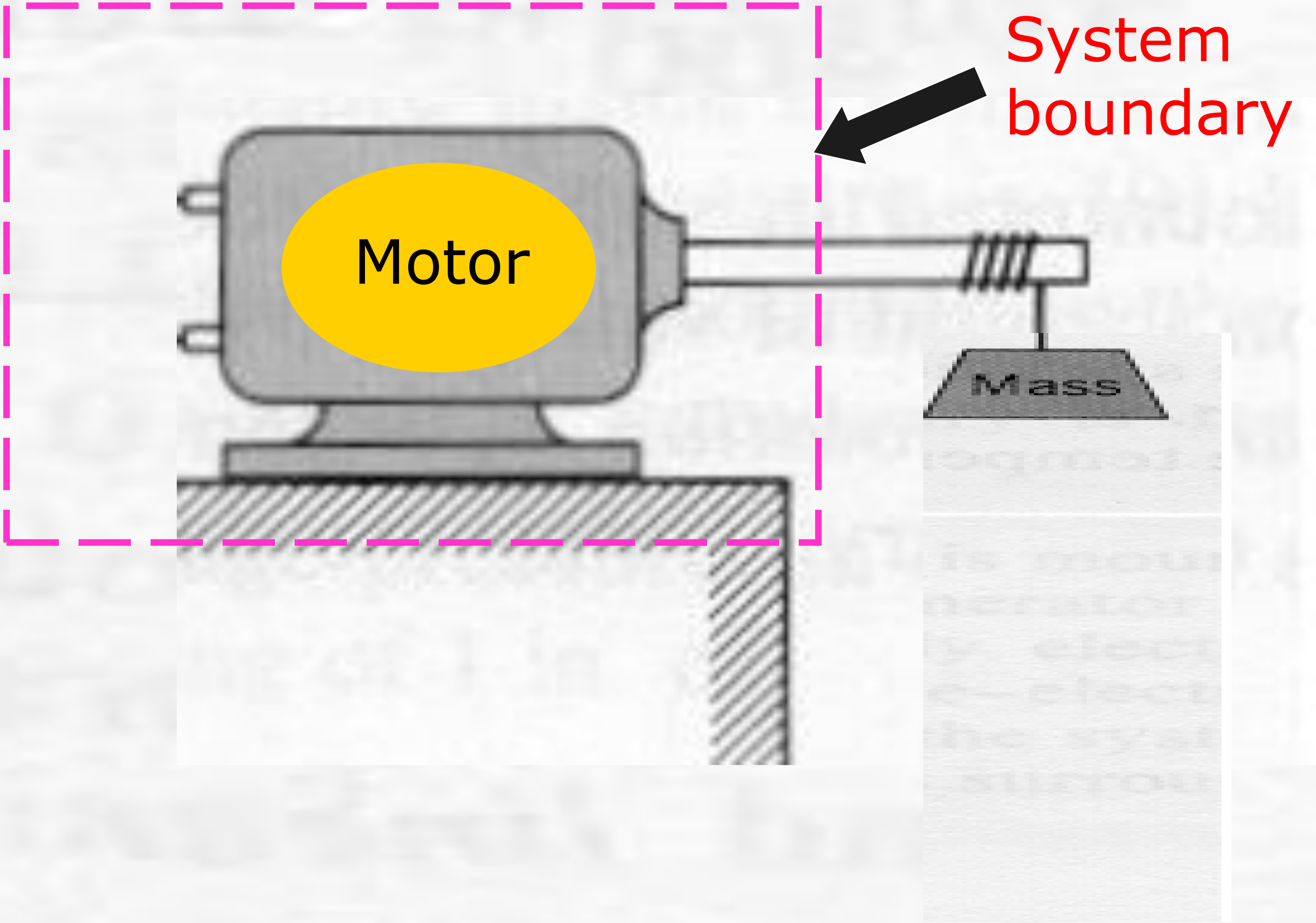
W_{out} is positive

m_{in} is positive

m_{out} is negative

WORK

Work--is done by a system (on its surroundings) **if** the sole effect on everything external to the system could have been the raising of a weight.


System
boundary
Motor
Mass

Remember!

W < 0 is work done **on** the system

W > 0 is work done **by** the system

You've seen work before in mechanics. It's **defined** in terms of force and displacement

$$W = \int \overline{F} \cdot d\overline{s}$$

Note that F and ds are vectors....

WHAT IS WORK AGAIN?

Work--an interaction between a system and its surroundings whose equivalent action can be the raising or lowering of a weight.

Path-dependent quantities

- Up to this point, what you've seen in calculus is primarily exact differentials
- Exact differentials are path-**in**dependent

$$\int_{S_1}^{S_2} ds = S_2 - S_1$$

Work is path dependent

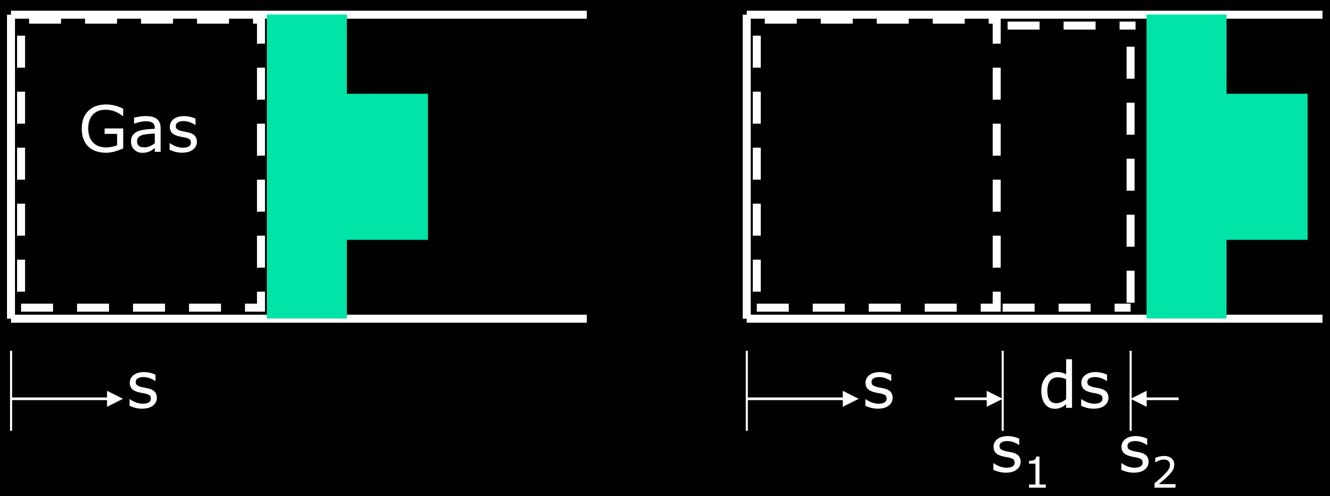
We use an inexact differential, δ, with work.

$$W = \int \delta(W)$$

Units of WORK

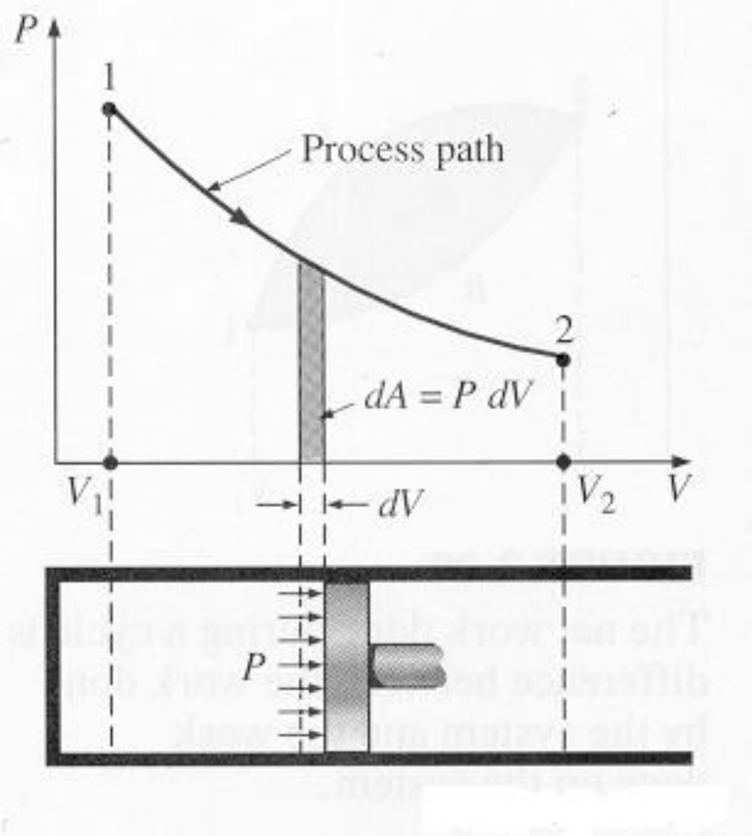
- Btu or kJ
- Rate of doing work, dW/dt, has units of Btu/h, ft-lb_f/h, J/s or Watts
- Rate of doing work is called **POWER**

Moving boundary work



A differential amount of volume is given by $dV = A_{piston} \times ds$

Moving boundary work



The area under the process curve on a *P*-*V* diagram represents the boundary work.

The force F on the piston is

$$F = P \times A_{piston}$$

Moving boundary work

$$W = \int_1^2 \bar{F} \cdot d\bar{s} = \int_1^2 F ds$$

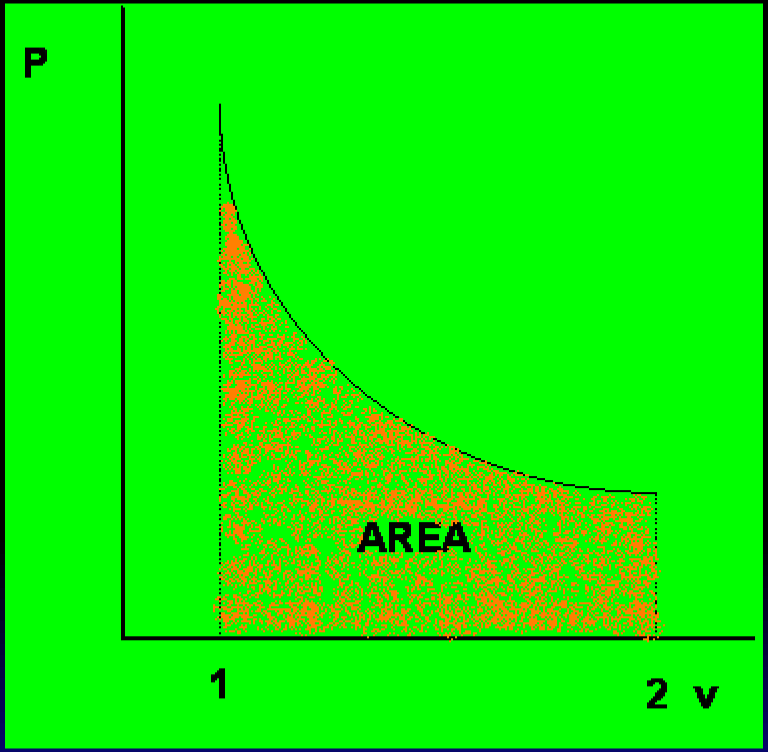
$$F = P \times A_{piston}$$

$$W = \int F ds = \int P \times A_{piston} ds$$

$$W = \int_1^2 P dV$$

dV

What did an integral represent in calculus?



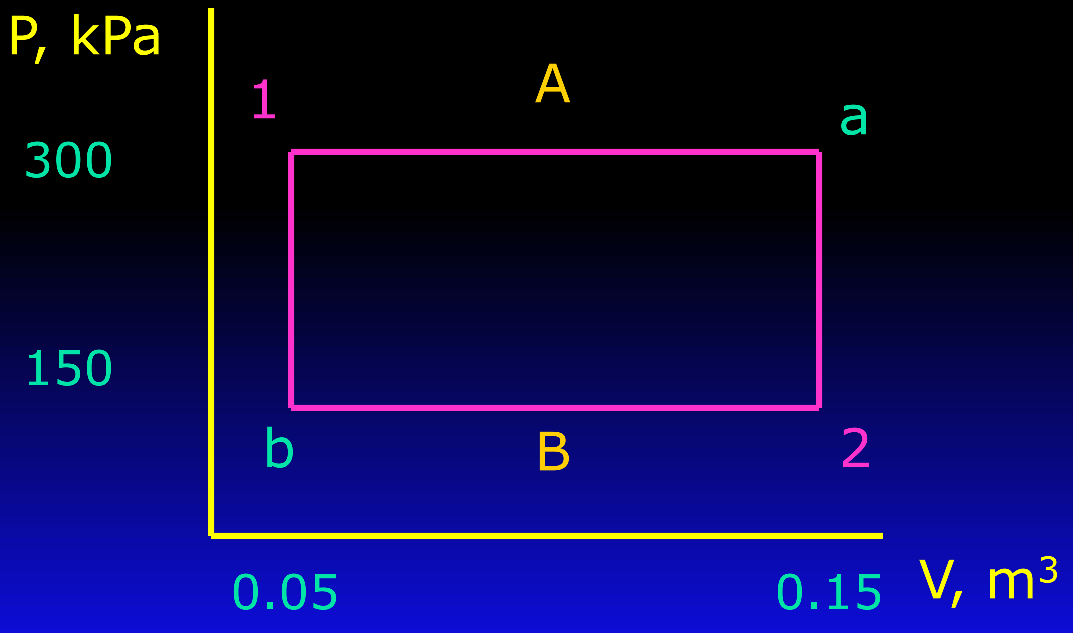
$$W = \int_{1}^{2} P dV$$

So,

if we know $p = p(V)$, then work due to compression can be interpreted as the area under a curve in pressure - volume coordinates.

TEAMPLAY

For a piston-cylinder system, two paths are shown from point 1 to 2. Compute the work in kJ done in going by path A from 1 to a to 2 (call the work W_A) and by path B from 1 to b to 2 (call the work W_B).



Moving boundary work

Work for a closed, compressible system is given by

$$W = \int_1^2 P\,dV$$

- *This has a variety of names:*
  - expansion work
  - PdV work
  - boundary work
  - compression work

Boundary work

To integrate for work, we must know the pressure as a function of the volume

$$\mathbf{P = P(V)}$$

This will give us the path of the work.

Some Common P(V) Paths

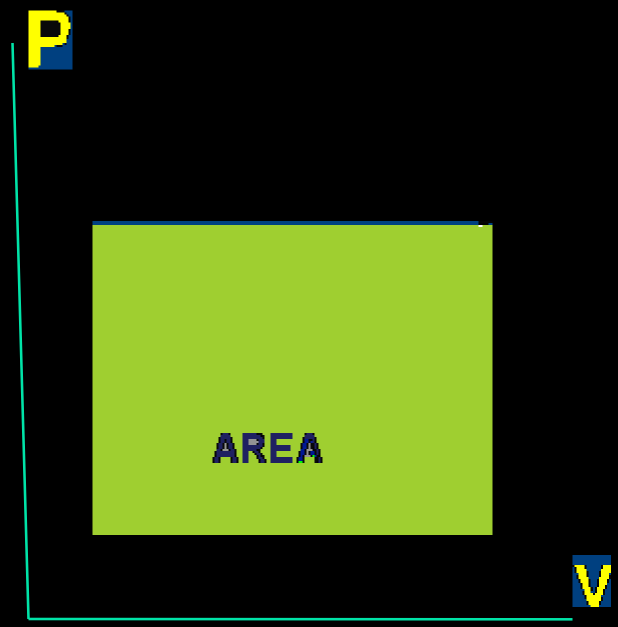
- $P=C$, constant pressure process
- $P=C/V$, ideal gas, const.temp. process
- $PV^n=C$, polytropic process

The constant pressure process is the easiest

Since P=c, it's pulled out of the integral

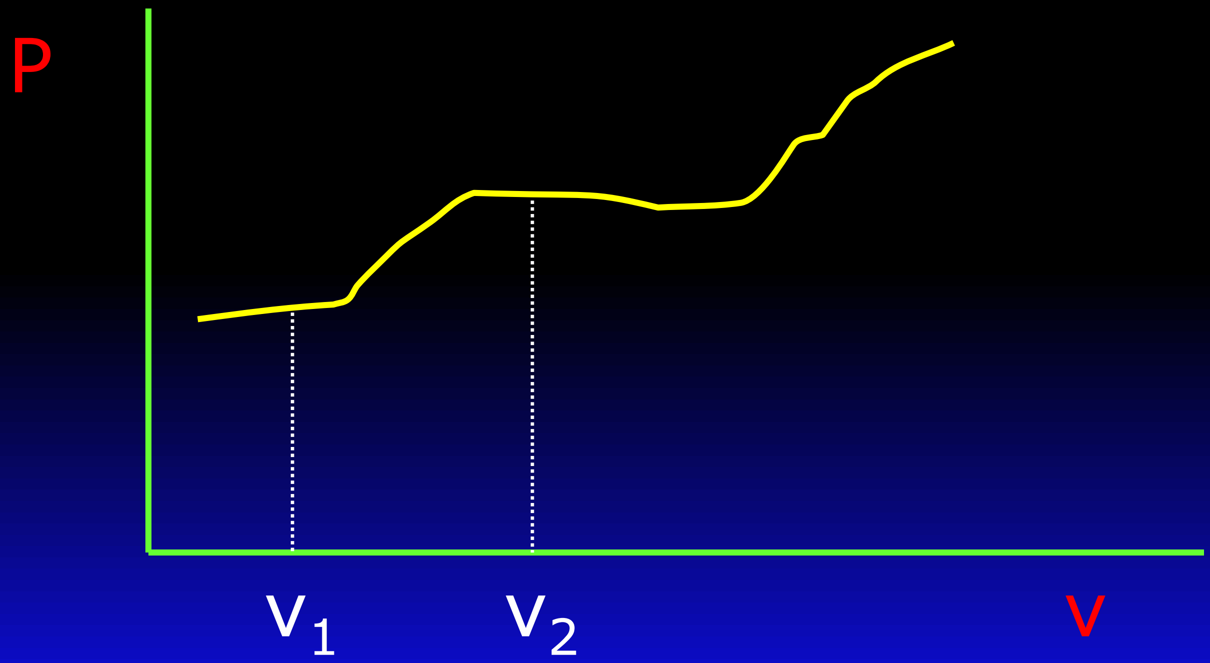
$$W = P\int_1^2 dV = P(V_2 - V_1)$$

YOU CAN ONLY DO THIS IF THE PRESSURE IS CONSTANT DURING THE PROCESS!



TEAMPLAY

How do you find the area under the curve (work) when the pressure isn't constant?
P = f(v) below?



Moving boundary work

Consider an ideal gas undergoing an isothermal process.

Start with the expression for work

$$W = \int_{1}^{2} p\,dV$$

For the gas, PV = mRT or $P = \frac{mRT}{V}$

$$W = \int_1^2 P dV = \int_1^2 \frac{mRT}{V} dV$$

Collecting terms and integrating yields:

$$W = mRT \int_1^2 \frac{dV}{V} = mRT \ln\left[\frac{V_2}{V_1}\right]$$

Note that this result is very different from the work for a constant pressure process!

TEAMPLAY

If you start at a P_1 and volume 1 and expand to a volume 2, which process will produce more work:

(a) a constant pressure or

(b) constant temperature process?

Why? Justify your answer.

Polytropic process

A frequently encountered process for gases is the polytropic process:

$$PV^n = c = \text{constant}$$

Since this expression relates P & V, we can calculate the work for this path.

$$W = \int_{V_1}^{V_2} P\,dV$$

General case of boundary work for a gas which obeys the polytropic equation

$$W = \int_1^2 P\,dV = c\int_1^2 \frac{dV}{V^n}$$

$$= \frac{P_2 V_2 - P_1 V_1}{1-n}$$

Other Forms of Work

Electrical Work

$$\frac{\delta W}{dt} = -VI$$

Shaft Work

$$\frac{\delta W}{dt} = -T\omega$$

Work and heat transfer

- Work is one way a system can interact with its surroundings.

- Another way is by means of **heat transfer**

HEAT TRANSFER

Heat is a form of energy transfer that occurs solely as a result of a temperature difference

$$Q = f(\Delta T)$$

Sign convention is the opposite of that for work:

- Q > 0: heat transfer to the system
- Q < 0: heat transfer from the system

*Heat transfer is **not** a property of a system, just as work is not a property.*

$$Q = \int_1^2 \delta Q \neq Q_2 - Q_1$$

We can't identify Q_2 (Q at state 2) or Q_1.

Heat energy can be transferred to and from the system or transformed into another form of energy.

Heat and work summary

- **They are only recognized at the boundary of a system, as they cross the boundary.**
- **They are associated with a process, not a state. Unlike u and h which have definite values at any state, q and w do not.**
- **They are both path-dependent functions.**
- **A system in general does not possess heat or work.**