First Law of Thermo for a C.M.

- The First Law of Thermodynamics for a Control Mass can be stated very simply:
  - **The change in energy of a control mass is the sum of the net work done on it and the net heat transfer to it.**
- The devil is in the details, of course!
- First consider the change in energy… what energy?
  - We will consider 3 types of energy: internal, kinetic, and potential. Or (using U to represent internal energy)

    E = I.E. + K.E. + P.E. = U + ½ mV^2 + mgz
- The change in energy is then ΔE, or, for a very small change, dE

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First Law for a C.M. (cont)

- Work can be either reversible or irreversible, but will be considered positive for work done on the C.M.
  - The total work done will be given the symbol W.
  - For a very small amount of work, we will use δW - the funny differential indicates this is a process, not a property!
- Similarly, the heat added, Q, will be positive for energy flowing into the C.M.
  - Since Q is also a process, a small amount of heat addition will be given the symbol δQ.
- Thus, symbolically, the First Law is:

$$\Delta E = W + Q \qquad \text{or} \qquad dE = \delta W + \delta Q$$

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Specific Heats

- The factors relating changes in temperature to the amount of heat added are called the **Specific Heats!**
  - Note this is the specific heat addition, q = Q/m!

$$\text{specific heat} = \frac{\delta q}{dT}$$

- Because heat addition is a process, we must also specify the conditions under which heat is added.
- If the process is at constant volume, it can be shown that δq = du (since work will be zero).
- Thus, we can write

$$\delta q = du = c_v dT$$

$$c_v = \text{specific heat at constant volume}$$

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Specific Heats (cont)

- Similarly, if the process is at constant pressure, which will usually mean volume increases as heat is added, then it can be shown that $\delta q = dh$
- Thus, we can write

$$\delta q = dh = c_p dT$$

$$c_p = \text{specific heat at constant pressure}$$

- The value of the specific heats lies in the fact that while c_v and c_p are defined for heat addition processes, the relationship to du and dh are always true!

$$du = c_v dT \qquad dh = c_p dT$$

Specific Heats (cont)

- Finally, the specific heats c_v and c_p will remain constant as long as the modes of internal energy storage remain the same.
- Thus, for a gas at conditions not near condensation or dissociation/ionization, we can integrate to get:

$$\int du = \int c_v dT \qquad \int dh = \int c_p dT$$

$$\Delta u = c_v \Delta T \qquad \Delta h = c_p \Delta T$$

- Typical values:
  - For air c_v = 718 J/kg/°R c_p = 1005 J/kg/°R
  - Note that $c_p - c_v = R$!

First Law of Thermo for a C.V.

- The First Law of Thermodynamics for a Control Volume is complicated by the fact that mass (and energy with it) can flow through the sides of the C.V.
- As a result, the First Law for a C.V. is stated in terms of rates and fluxes:
  - **The rate of change of the energy in a control volume is equal to the sum of the net energy flux into it plus the net work rate done on it plus the net heat transfer rate to it.**
- This will obvious require a bit of dissection to understand each contribution to the whole.

First Law for a C.V. (cont)

- The rate of change of energy in the C.V. is simply

$$\frac{dE}{dt} = \frac{d}{dt}(U + \tfrac{1}{2}mV^2 + mgz)$$

- The net flux of energy through the boundaries will be written as the product of the specific energy and mass flow rate into the C.V.,

$$\text{energy flux} = \sum_{boundaries} \dot{m}(u + \tfrac{1}{2}V^2 + gz)$$

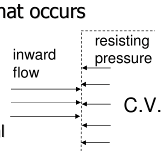
- Note that mass flow is considered positive for an influx. Mass flow outward would have a negative value.

First Law for a C.V. (cont)

- The heat addition is the same, except now a rate:

$$\text{heat transfer rate} = \dot{Q}$$

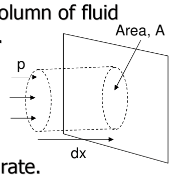
- The rate of doing work will include the same types of work associated with a C.M., but also a new form of work - Flow Work.
- To understand flow work, consider what occurs where flow enters our C.V.
  - Mass is being forced into the C.V. against the resistance of pressure.
  - The difference is that this is work the flow does on itself, not by some external source!



First Law for a C.V. (cont)

- To calculate flow work, consider a column of fluid being forced into the C.V. as shown.
- The incremental flow work rate is:

$$\delta(\text{flow work}) = \frac{pAdx}{dt} = p\dot{\mathcal{V}} = pv\dot{m}$$



- Where the $\mathcal{V}$ dot is the volume flow rate.
- Thus, the total rate of doing work can be expressed by the sum of our old work rate plus flow work:

$$\text{work rate} = \dot{W} + \sum_{boundaries} pv\dot{m}$$

First Law for a C.V. (cont)

- So, to summarize the First Law for a C.V.,

$$\frac{dE}{dt} = \dot{Q} + \dot{W} + \sum_{boundaries} \dot{m}pv + \sum_{boundaries} \dot{m}(u + \frac{1}{2}V^2 + gz)$$

- Or, even simpler, since h = u + pv

$$\boxed{\frac{dE}{dt} = \dot{Q} + \dot{W} + \sum_{boundaries} \dot{m}(h + \frac{1}{2}V^2 + gz)}$$

- In practice, this relation is even easier since most problems are steady state such that dE/dt = 0!

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