Energy, Work, & Heat

→ Last time we introduced systems & balances. We found that with a carefully defined system we could balance just about anything.

→ Today we will begin to quantify & balance Energy ⟸ the 1st Law of thermo

→ What is energy? → Well what forms of energy are there?

→ Thermal, potential, kinetic, mechanical, electrical, chemical, nuclear.....

☆ → All of these forms are quantifiable relative to a reference state & can be included in thermodynamic systems. Energy has units of J = N-m

→ There are many definitions for energy & what it is, my definition: energy is a gradient in anything. Your book defines energy as the potential to produce change.

☆ These forms of energy can be divided into categories:

Internal: dependent on the atoms & molecules of the material in the system → thermal, chemical, nuclear → we won't use these much

External: dependent on the system surroundings/Reference state → Potential, kinetic, electrical, mechanical, etc.

→ Can energy transfer between these forms? Yes!

→ Can energy transfer between systems? Yes!! but how?

☆ Heat: energy transfer through a temperature differential

☆ Work: energy transfer across a system boundary as a result of a difference in any potential other than temperature.

→ We need to balance energy for a system that includes allof the ways that energy changes

closed system

$E_{in} \Rightarrow \Delta E_{stored} \Rightarrow E_{out}$

Balance: $E_{in} + \cancelto{0}{E_{produced}} = E_{out} + \cancelto{0}{E_{destroyed}} + \Delta E_{stored}$

is energy produced or destroyed? No its conserved.

$\Rightarrow E_{in} = E_{out} + \Delta E_{stored}$ where $E_{in} = Q_{in} + W_{in}$, $E_{out} = Q_{out} + W_{out}$

$\Delta E_{stored} = ?$ Thermal $= \Delta U \leftarrow$ internal energy of a system

Potential $= \Delta PE = mg\Delta z$

Kinetic $= \Delta KE = \frac{1}{2}mv^2$

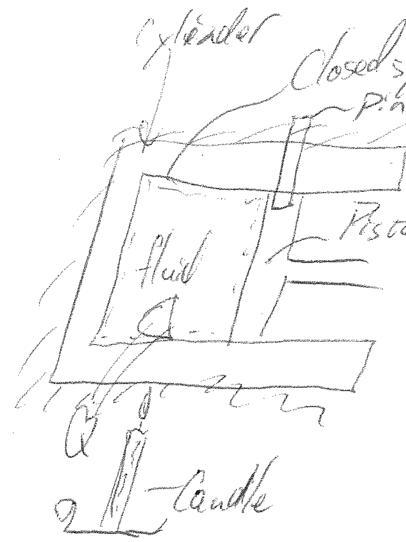
→ Our Incremental energy balance on a closed system is then

$$\underbrace{Q_{in} + W_{in}}_{E_{in}} = \underbrace{Q_{out} + W_{out}}_{E_{out}} + \underbrace{\Delta U + \Delta PE + \Delta KE}_{\Delta E_{stored}}$$

→ On a rate basis for a closed system

$$\underbrace{\dot{Q}_{in} + \dot{W}_{in}}_{\text{Rate of Energy in}} = \underbrace{\dot{Q}_{out} + \dot{W}_{out}}_{\text{Rate of energy out}} + \underbrace{\frac{dU}{dt} + \frac{dPE}{dt} + \frac{dKE}{dt}}_{\text{Rate change of energy stored}}$$

Let's work through some examples

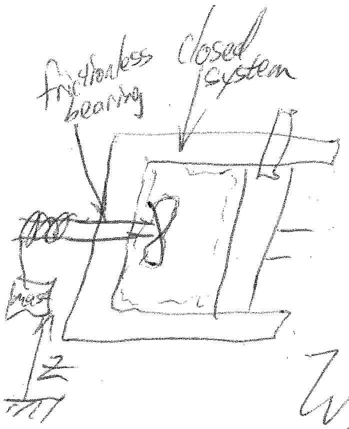


For the purposes of this class heat transfer will either be

1) neglected / adiabatic system — adiabatic means no heat transfer $Q=0$
2) Specified / given to you
3) The quantity that is being calculated in the balance

Simple enough. How else can we transfer energy to the system?

$\Rightarrow$ Work ← how Let's add a shaft with a propeller. The shaft transfers mechanical energy via torque × speed to the fluid. How do we spin the shaft with one of our energy forms?

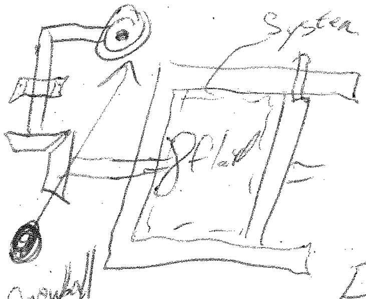


Potential: Falling weight. How do we find the work transferred by the falling weight? Work has units of Joules $J = N{\cdot}m$, force through distance

$$W_{1\to2}=\int_{z_1}^{z_2} F\,dz \Rightarrow W_{1\to2}=\overbrace{F}^{F=mg}(z_2-z_1) \Rightarrow W_{1\to2}=mg(z_2-z_1)$$

So our fluid energy balance becomes $E_{in}=\cancel{E_{out}}^{0}+\Delta E_{stored}$

$$\Rightarrow \cancel{Q_{in}}^{0}+W_{in}=\Delta U+\cancel{\Delta KE}^{0}+\cancel{\Delta PE}^{0} \Rightarrow W_{in}=\Delta U \Rightarrow \Delta U=mg(z_2-z_1)$$



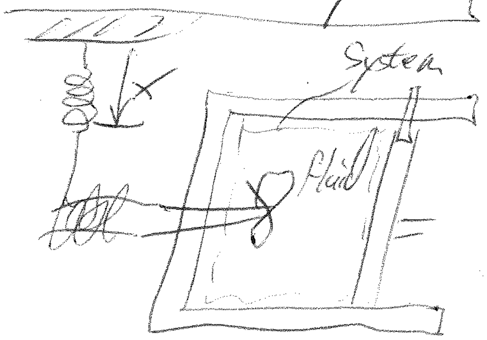
Kinetic: Snowball hitting target.

Newton's 2nd Law: $F=m\frac{dv}{dt}$ where $v=\frac{dx}{dt}$ applying chain rule $\frac{dv}{dt}=\frac{dv}{dx}\underbrace{\left(\frac{dx}{dt}\right)}_{=v}$

$$F=m\frac{dv}{dx}\frac{dx}{dt} \Rightarrow F=mv\frac{dv}{dx} \;\&\; W_{1\to2}=\int_{x_1}^{x_2}F\,dx \Rightarrow$$

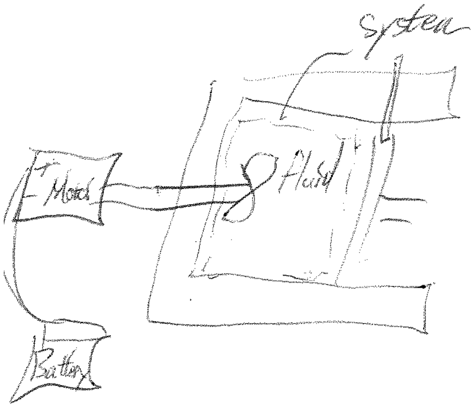
$$\Rightarrow W_{1\to2}=\int_{v_1}^{v_2} mv\frac{dv}{\cancel{dx}}\cancel{dx} \Rightarrow W_{1\to2}=\frac{m}{2}\left(v_2^2-v_1^2\right)=\Delta U \text{ in balance}$$

3.4 ME 301 Sp 2014



Mechanical: Spring & String: Hooke's Law $F=kx$

So $W_{1\to2}=\int_{x_1}^{x_2} F\,dx \Rightarrow W_{1\to2}=\int_{x_1}^{x_2} kx\,dx \Rightarrow W_{1\to2}=\frac{k}{2}\left(x_2^2-x_1^2\right)$



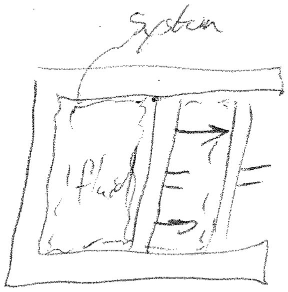
Electrical: Motor: usually measured by power meter

$1\text{ Watt}=1\frac{J}{s}$ $\quad \dot{W}=\frac{dW}{dt} \Rightarrow W_{1\to2}=\int_{t_1}^{t_2}\dot{W}\,dt = \underbrace{\Delta U}_{\text{in balance}}$

→ Your book has many more!!

Is there another way to do work on the system besides the shaft?

→ What happens if the piston moves & our system volume changes size?



$W_{1\to2}=\int_{x_1}^{x_2} F\,dx$ where $F=\overset{\text{Pressure}}{P}\,\overset{\text{area}}{A} \Rightarrow W_{1\to2}=\int_{x_1}^{x_2} PA\,dx$ & $d\overset{\text{Volume}}{V}=A\,dx$

$W_{1\to2}=\int_{V_1}^{V_2} P\,dV$ ← to solve this we need a relationship for pressure as a function of volume for our fluid.

We don't know how ~~to do this yet~~ these properties are related yet! Moreover, it in all of these specific cases $W_{1\to2}=\Delta U$ → What is internal energy & how is it related to the other properties? like T & P?

We will discuss this next week! Discussion & HW due Wednesday.