CH365 Chemical Engineering Thermodynamics

Lesson 5
Reversible Processes

Professor Andrew Biaglow
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Equilibrium

Hidden Material – Take Notes!

Equilibrium is the absence of any tendency toward change in a macroscopic scale

The Reversible Process

A process is reversible when its direction can be changed at any point by an infinitesimal change in external conditions.

Note: $P_{external} \approx P_{internal}$

- frictionless piston
- no heat transfer to surroundings
- no gravity

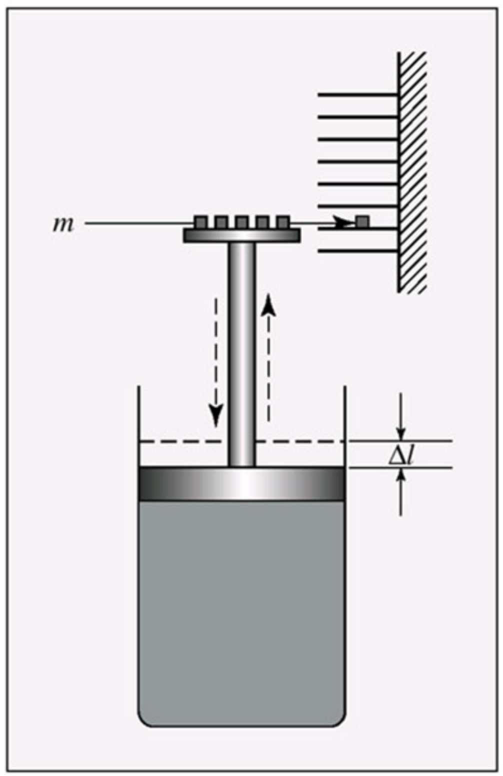

Figure 2.2: Expansion of a gas.

Attributes of a Reversible Process

A reversible process:

- can be reversed at any point by an infinitesimal change in external conditions
- is never more than minutely removed from equilibrium
- traverses a succession of (infinitesimally different) equilibrium states
- is frictionless
- is driven by forces whose imbalance is infinitesimal in magnitude
- proceeds infinitely slowly
- when reversed, retraces its path, restoring the initial state of the system and the surroundings

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$$dW = -PdV \Longrightarrow W = -\int_{V_1^t}^{V_2^t} PdV \quad \text{or} \quad W = -P\Delta V$$

Eq 1.3

Eq 1.4

When?

Example 2.5

Hidden Material – Take Notes!

A horizontal piston/cylinder arrangement is placed in a constant-temperature bath. The piston slides in the cylinder with negligible friction, and an external force holds it in place against an initial pressure of 14 bar. The initial gas volume is 0.03 m^3. The external force on the piston is reduced gradually, and the gas expands isothermally as its volume doubles. If the volume of gas is related to its pressure so that the product PV^t is constant, what is the work done by the gas in moving the external force?

Example 2.5, continued

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How much work would be done if the external force were suddenly reduced to half its initial value (7 bar) instead of being gradually reduced?

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Lesson 5 Problems

Problem 2.9

Heat in the amount of 7.5 kJ is added to a closed system while its internal energy decreases by 12 kJ. How much energy is transferred as work? For a process causing the same change of state but for which the work is zero, how much heat is transferred?

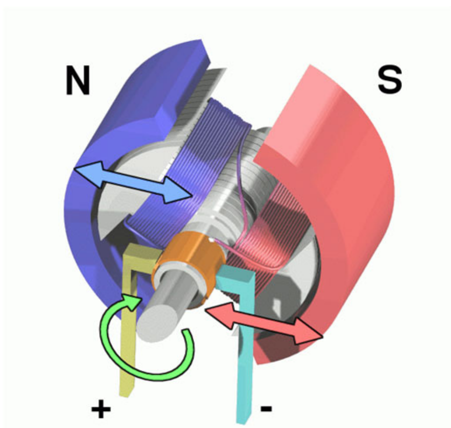
Problem 2.11

An incompressible fluid (ρ = constant) is contained in an insulated cylinder fitted with a frictionless piston. Can energy as work be transferred to the fluid? What is the change in internal energy of the fluid when the pressure is increased from P1 to P2?

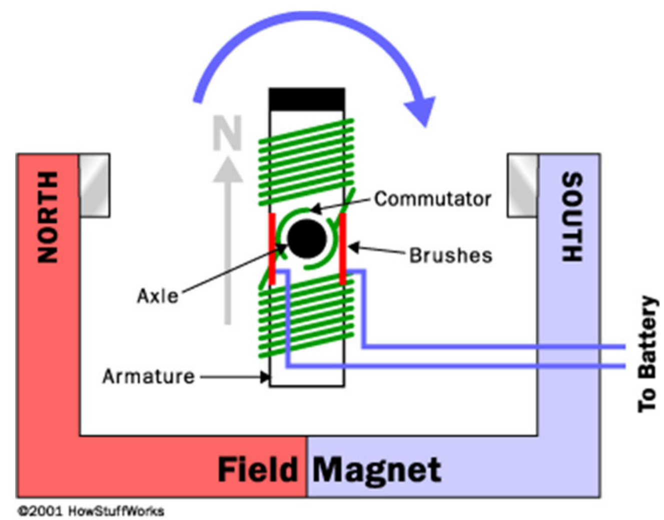
Problem 2.13

An electric motor runs "hot" under load, owing to internal irreversibilities. It has been suggested that the associated energy loss can be minimized by thermally insulating the motor casing. Comment critically on this suggestion.

https://www.machinedesign.com



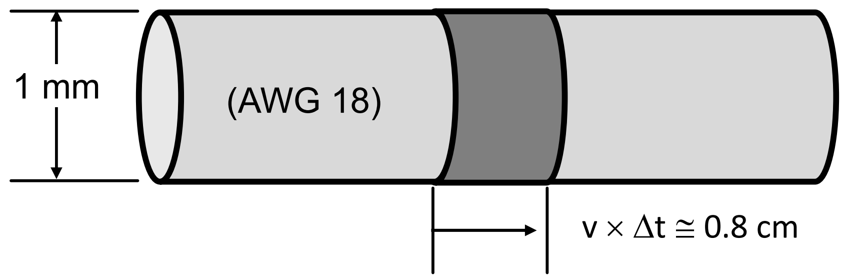
https://en.wikipedia.org/wiki/Electric_motor



https://electronics.howstuffworks.com/motor1.htm

Why does copper wire heat up from current flow?

From Ohm's Law V=IR, at fixed voltage, increasing resistance decreases current. From Joule's Law, P=IV, decreasing current at fixed voltage decreases P ("ohmic" or "joule" heating), i.e., the energy per time converted from electrical energy to thermal energy.



AWG Gauge*	Diameter (mils, 1000th in)	Electrical Resistance (Ohms/1000 ft) (Ohms/1000m)	
		at 77°F (25°C)	at 149°F (65°C)
13		2.04	
14	64	2.58	2.97
15		3.25	
16	51	4.09	4.73
17		5.16	
18	40	6.51	7.51
19		8.21	
20	32	10.4	11.9
21		13.1	
22	25.3	16.5	19.0

https://www.engineeringtoolbox.com

Current is related to the velocity of the electrons

$$\frac{\dfrac{\text{electrons}}{\text{s}}}{\dfrac{\text{electrons}}{\text{m}^3}} = \frac{\text{m}^3}{\text{s}} \qquad \frac{\dfrac{\text{electrons}}{\text{second}}}{\dfrac{\text{electrons}}{\text{m}^3}\cdot \text{m}^2} = \frac{\text{m}}{\text{s}}$$

Each copper atom contributes roughly two free electrons that can move through the wire. Furthermore, atoms of copper are about 1 nm apart. This makes the density of free electrons, n, about $10^{27}/\text{m}^3$.

I	current	amps
Δt	time interval	sec
q	charge of one electron	1.6×10^{-19} C/e-
n	density of free electrons	10^{27} e-/m^3
A	cross-sectional area of the wire	m^2
v	speed of the electrons in the wire	m/sec

$$v = \frac{I}{q\cdot n\cdot A} = \frac{1\text{amp}\cdot\dfrac{1\text{C}/\text{s}}{\text{amp}}}{\dfrac{1.6\times10^{-19}\,\text{C}}{\text{electron}}\cdot\dfrac{10^{27}\,\text{electrons}}{\text{m}^3}\cdot\dfrac{\pi(.001\text{m})^2}{4}} = 0.0080\,\frac{\text{m}}{\text{s}} \sim 1\,\frac{\text{cm}}{\text{s}}$$

(increasing resistance decreases current, which decreases velocity).

Kinetic energy is related to velocity. Lower velocity indicates lower kinetic energy, which is lost by collisions with the atoms of the conductor. Lost kinetic energy takes the form of heat through increased vibrations of atoms of copper, leading to increased temperature.