CAE 208 / MMAE 320: Thermodynamics
Fall 2023

August 29, 2023
Basic Concepts of Thermodynamics (2)

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ANNOUNCEMENTS

Announcements

- Assignment 1 is due this coming Thursday

Announcements

- Respond to the TA office hour today by 5 pm

Announcements

RECAP

Recap

- A system is defined as quantity of matter or a region in space chosen for study
  - ❑ Closed system known as “control mass”
  - ❑ Open system known as “control volume”

- A few important aspects of a system: Boundary (movable or fixed) and surrounding

PROPERTY OF A SYSTEM

Properties of a System

- Property = Any characteristics of a system
  - ❑ Pressure (P)
  - ❑ Temperature (T)
  - ❑ Volume (V)
  - ❑ .
  - ❑ .
  - ❑ .
  - ❑ Thermal conductivity (k)

Properties of a System

- Properties are.
  - ❑ Intensive: Independent of mass
  - ❑ Extensive: Depends on the size – extent - of a system

Properties of a System

- Can we convert an extensive property to an intensive property?

DENSITY AND SPECIFIC GRAVITY

Density and Specific Gravity

- Density = Mass per unit volume
- Specific volume = Volume per mass

Density and Specific Gravity

- What is the density of water and air?

Material	SI (kg/m^3)	IP (lb/ft^3)
Water	997	62.4
Air	1.2754	0.763

Density and Specific Gravity

- Density as a function of pressure and temperature

Phase	Temperature	Pressure
Gas	Inversely proportional	Proportional
Liquid	Negligible but dependent	Less dependent
Solid	Negligible but dependent	Less dependent

Density and Specific Gravity

- Specific gravity or relative density is the ratio of the density of a substance to the density of some standard substance at a specific temperature (usually water 4°C and ρ = 1000)

$$SG = \frac{\rho}{\rho_{H2O}}$$

Density and Specific Gravity

- Specific weight

$$\gamma_s = \rho g$$

CLASS ACTIVITY

Class Activity

- The density of water liquid is defined as $\rho = 1000 - \frac{T}{2}$ with T in Celsius. If the temperature increases, what happens to the density and specific volume.

CLASS ACTIVITY

Class Activity

- A 1 m^3 container is filled with 0.12 m^3 of granite, 0.15m^3 of sand and 0.2 m^3 of liquid water at 25 °C, and the rest of the volume, 0.53 m^3, is air. Find the overall (average) specific volume and density.

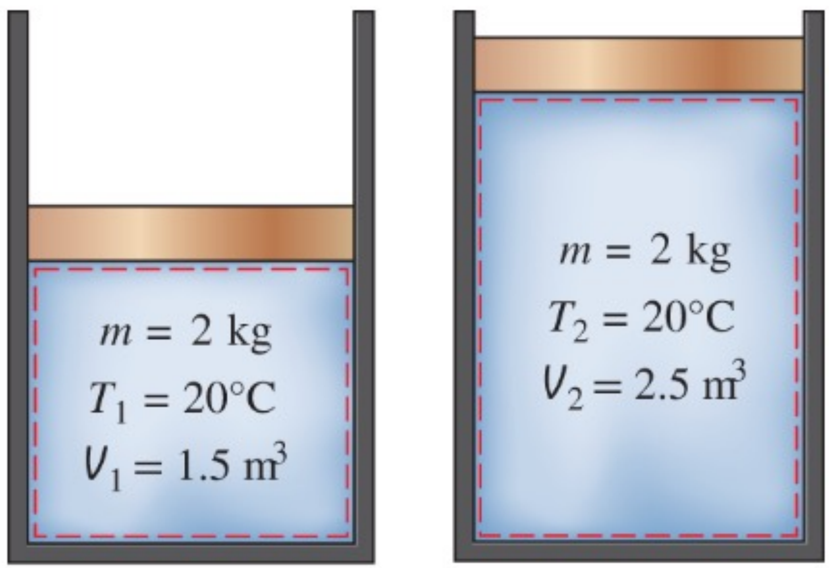
- The following densities could be used for the calculations
  - ❑ $\rho_{granite} = 2750 \frac{kg}{m^3}$
  - ❑ $\rho_{sand} = 1500 \frac{kg}{m^3}$
  - ❑ $\rho_{water} = 997 \frac{kg}{m^3}$
  - ❑ $\rho_{air} = 1.15 \frac{kg}{m^3}$

Class Activity

STATE AND EQUILIBRIUM

State and Equilibrium

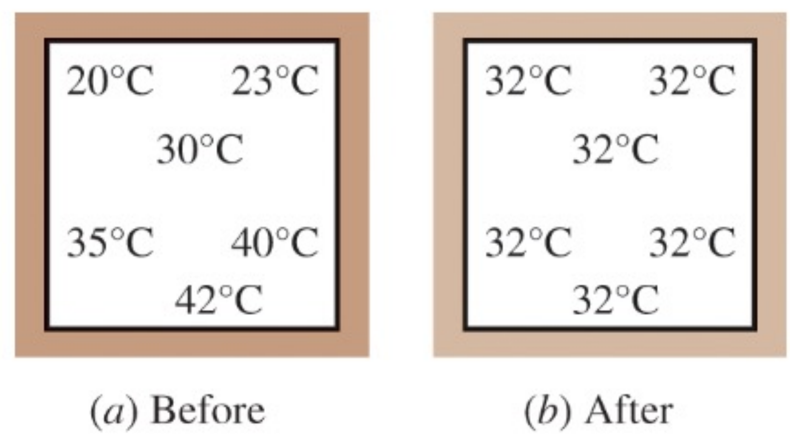
- Consider a system that is not undergoing any change
  - ❑ All properties can be measured
  - ❑ Given a set of properties we can describe the condition or the state of the system
  - ❑ All properties are fixed till one of them changes



(a) State 1 (b) State 2

State and Equilibrium

- Thermodynamics deals with equilibrium states
- Equilibrium means a state of balance, meaning no driving forces or unbalanced potential
  - ❑ Thermal equilibrium
  - ❑ Mechanical equilibrium
  - ❑ Phase equilibrium
  - ❑ Chemical equilibrium



State and Equilibrium

- The number of properties required to fix the state of a system is given by the state postulate:

The state of a simple compressible system is completely specified by two independent, intensive properties

- Simple compressible system in the absence of electrical, agentic , gravitational, motion, and surface tension

State and Equilibrium

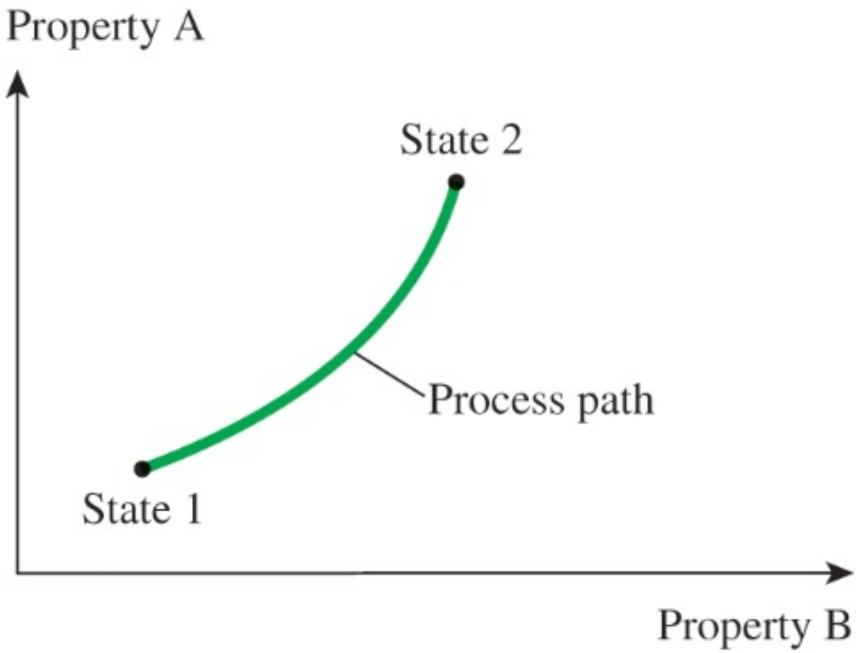
- Two independent "intensive" properties
  - ❑ Temperature and specific volume
  - ❑ Temperature and pressure for a single phase
  - ❑ Temperature and pressure are not independent for a multiphase system

PROCESSES AND CYCLES

Processes and Cycles

- Any change that a system undergoes from one equilibrium state to another is called process

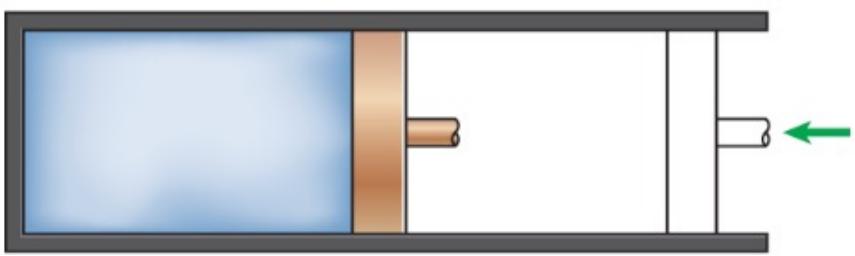
- A series of states through which a system passes during a process is called the path of the process



Processes and Cycles

- Quasi-equilibrium vs. nonquasi-equilibrium

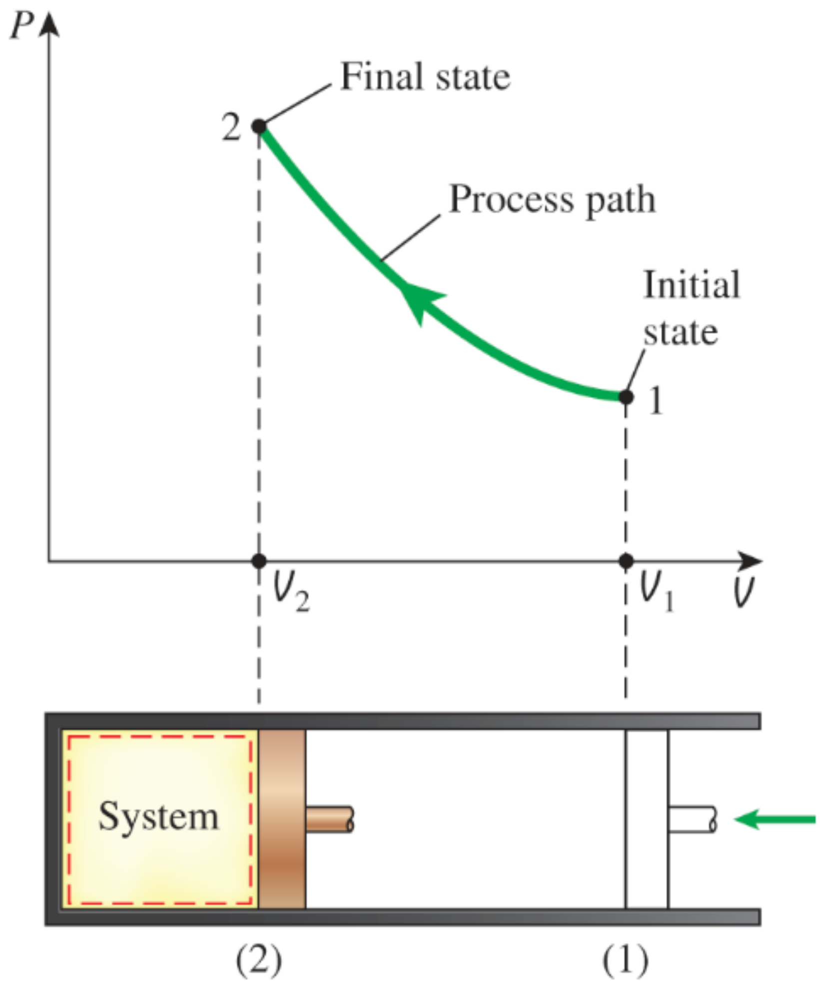
(*a*) Slow compression
(quasi-equilibrium)



(*b*) Very fast compression
(nonquasi-equilibrium)

Processes and Cycles

- Process diagrams



Processes and Cycles

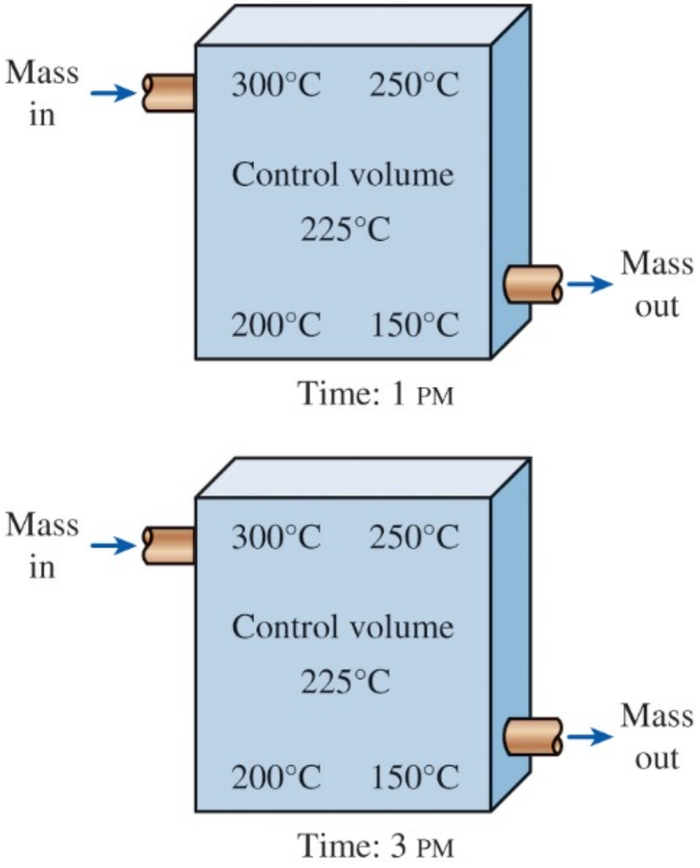
- “iso-” is often used to designate a process for which a particulate property remains constant
  - Isothermal process: A constant temperature process
  - Isobaric process: A constant pressure process
  - Isomeric process: A constant specific volume process

Processes and Cycles

- A system is called a cycle if it returns to its initial state at the end of the process (initial and final states are identical)

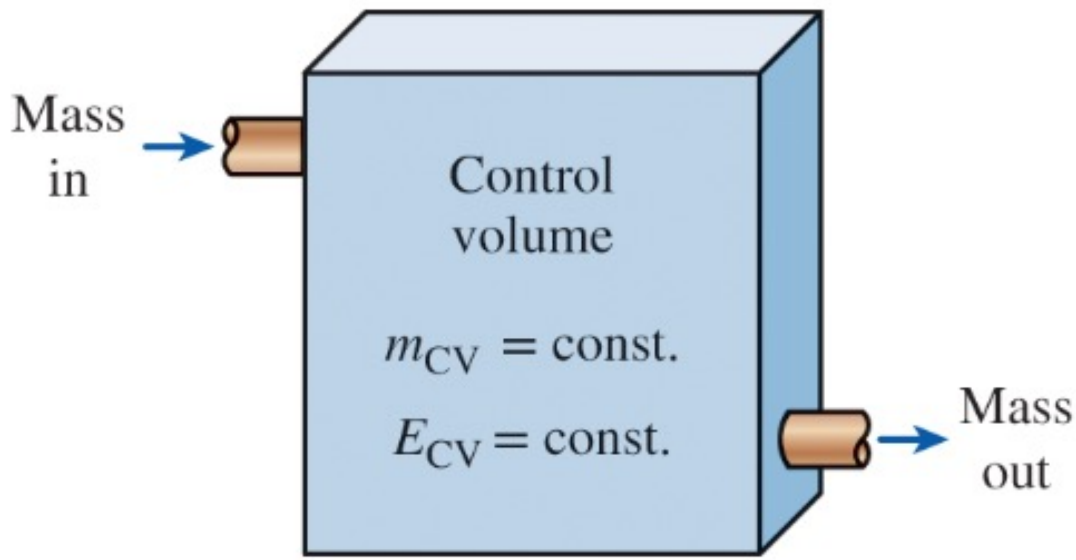
Processes and Cycles

- Steady-flow or steady-state process = no change with time



Processes and Cycles

- Steady-flow or steady-state process



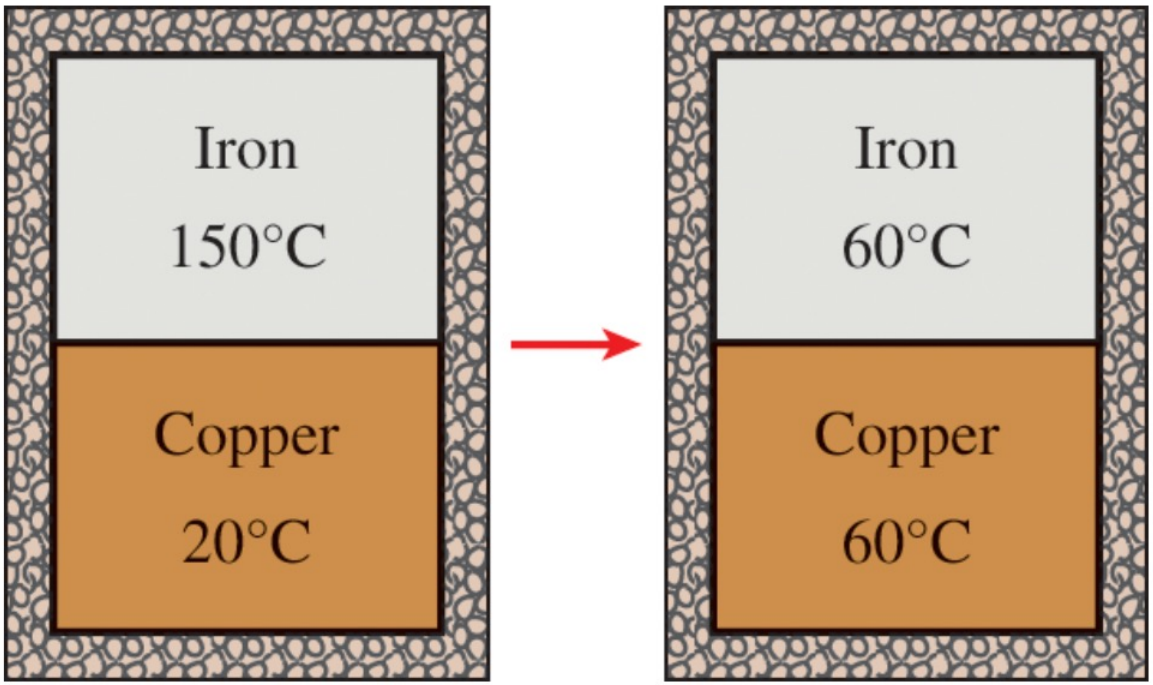
Processes and Cycles

- Can we call steady-flow and uniform the same?

TEMPERATURE AND THE ZEROTH LAW OF THERMODYNAMICS

Temperature and the Zeroth Law of Thermo

- We need scales to accurately measure temperature based on repeatable and predictable ways



Thermal equilibrium

Temperature and the Zeroth Law of Thermo

Zeroth Law of Thermodynamics: If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other

OR

Zeroth Law of Thermodynamics: If we replace the third body with a thermometer, the two bodies are in thermal equilibrium if both have the same temperature readings even if they are not in contact

Temperature and the Zeroth Law of Thermo

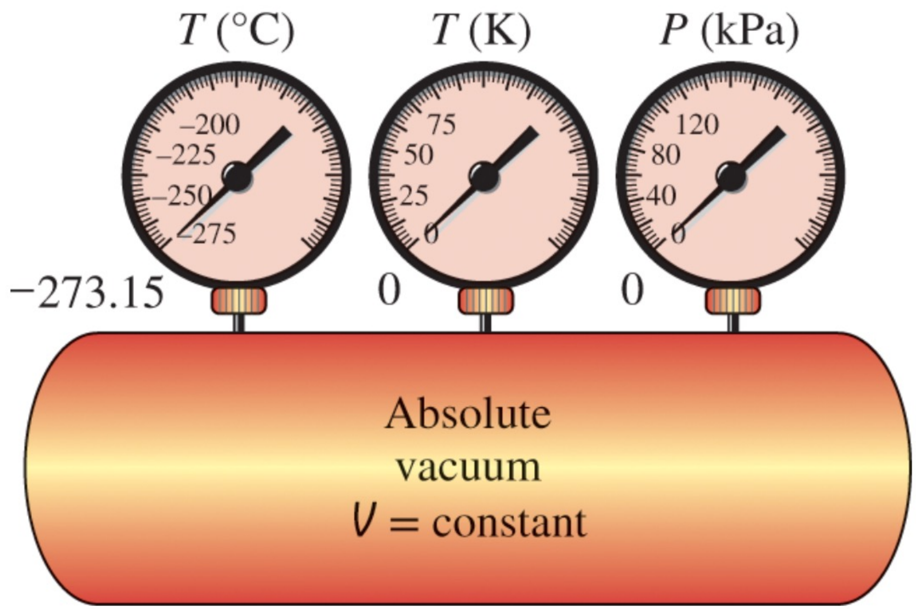
- Common temperature scales use ice and steam points for water

Temperature and the Zeroth Law of Thermo

- In thermodynamics the desire is to have a temperature scale known as the “thermodynamics temperature scale” that is independent of any substance or substances

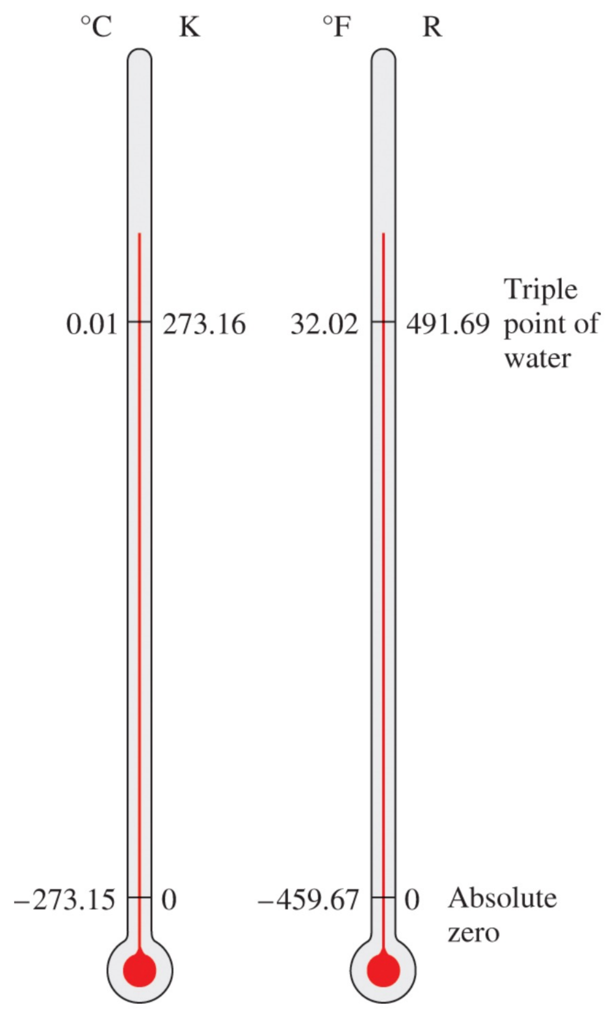
Temperature and the Zeroth Law of Thermo

- A temperature scale that is nearly identical to the Kevin scale is the ideal-gas temperature scale



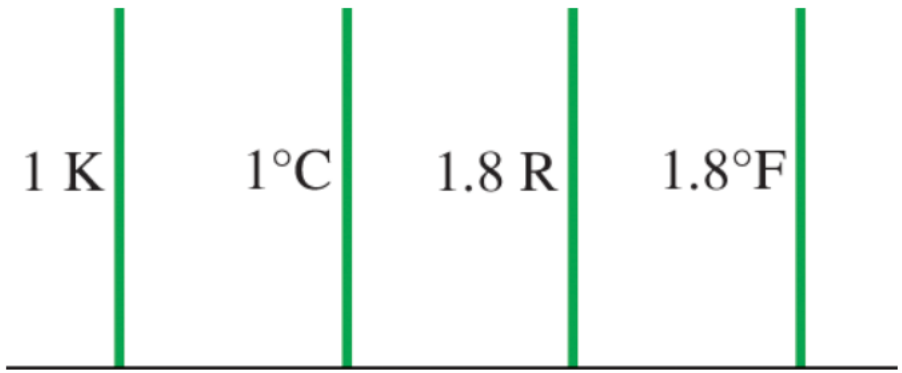
Temperature and the Zeroth Law of Thermo

- Ideal gas temperature



Temperature and the Zeroth Law of Thermo

- Temperature difference



CLASS ACTIVITY

Class Activity

- A system goes from 68 °F to 77 °F. Calculate the temperature difference in °F, °C, K, R

PRESSURE

Pressure

- Pressure is defined as a normal force exerted by a fluid per unit area

Pressure

- Other units

$$1\ bar = 10^5 Pa = 0.1\ MPa = 100\ kPa$$

$$1\ atm\ = 101{,}325\ Pa = 101.325\ kPa$$

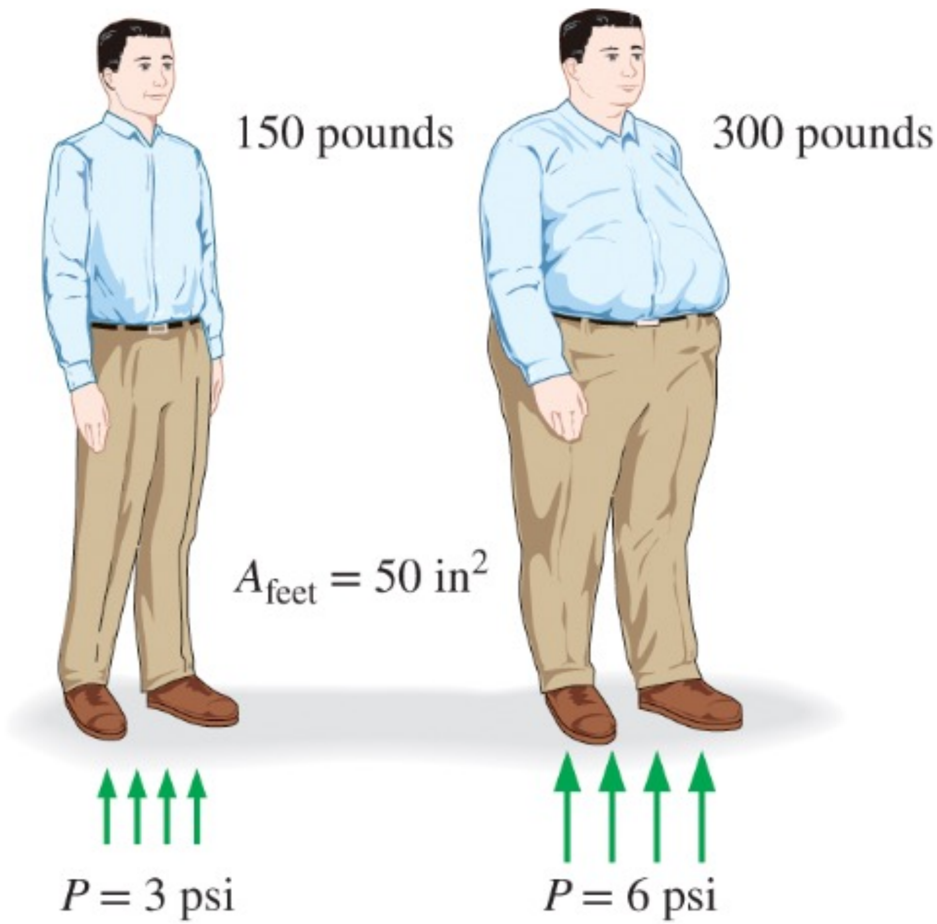
$$1\,\frac{kgf}{cm^2} = 0.9807\ bar = 0.9679\ atm$$

Pressure

- IP units

$$1\ atm = 14.696 \frac{lbf}{in^2}\ (or\ psi)$$

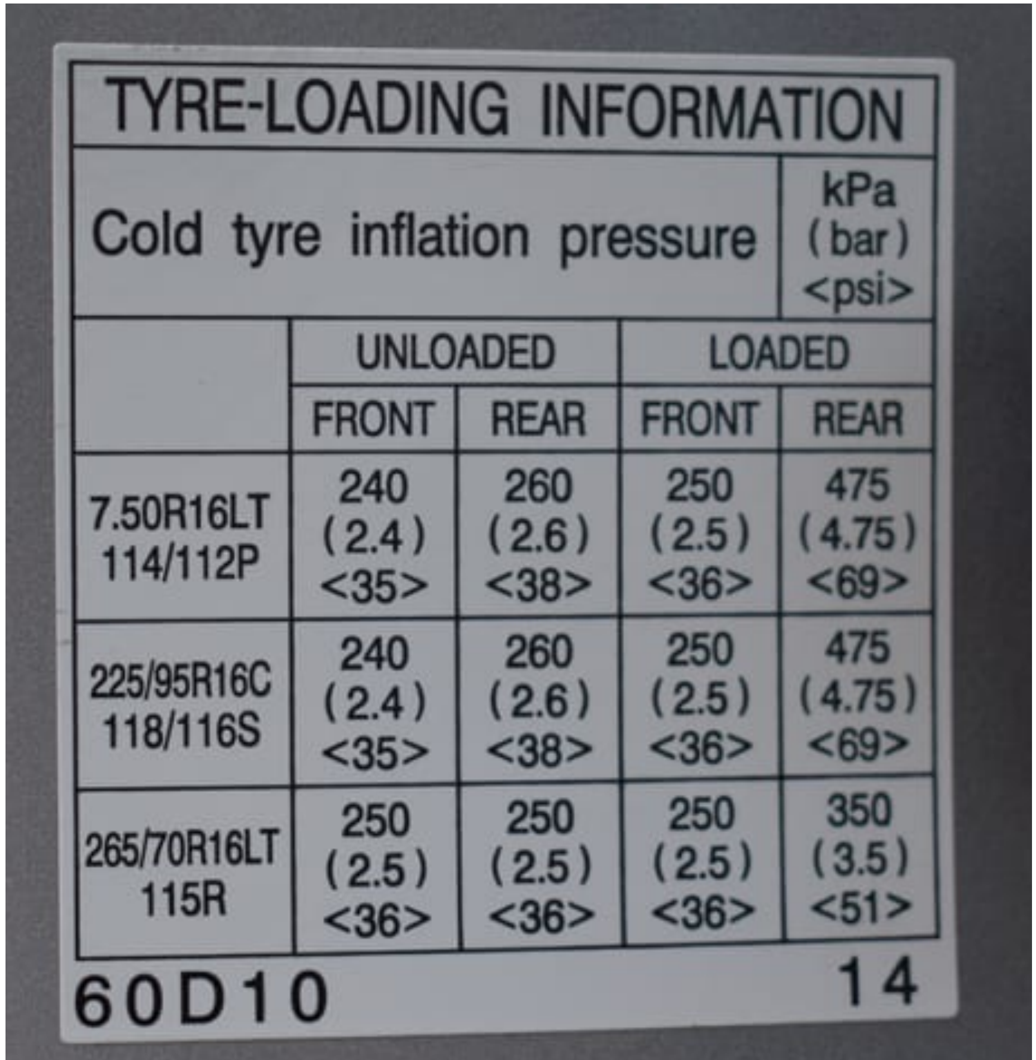
Pressure



$$P = \sigma_n = \frac{W}{A_{feet}} = \frac{150 \text{ lbf}}{50 \text{ in}^2} = 3 \text{ psi}$$

Pressure

- How much air do we put in car and bike tires?



TYRE-LOADING INFORMATION

Cold tyre inflation pressure				kPa (bar) <psi>
	UNLOADED		LOADED	
	FRONT	REAR	FRONT	REAR
7.50R16LT 114/112P	240 (2.4) <35>	260 (2.6) <38>	250 (2.5) <36>	475 (4.75) <69>
225/95R16C 118/116S	240 (2.4) <35>	260 (2.6) <38>	250 (2.5) <36>	475 (4.75) <69>
265/70R16LT 115R	250 (2.5) <36>	250 (2.5) <36>	250 (2.5) <36>	350 (3.5) <51>

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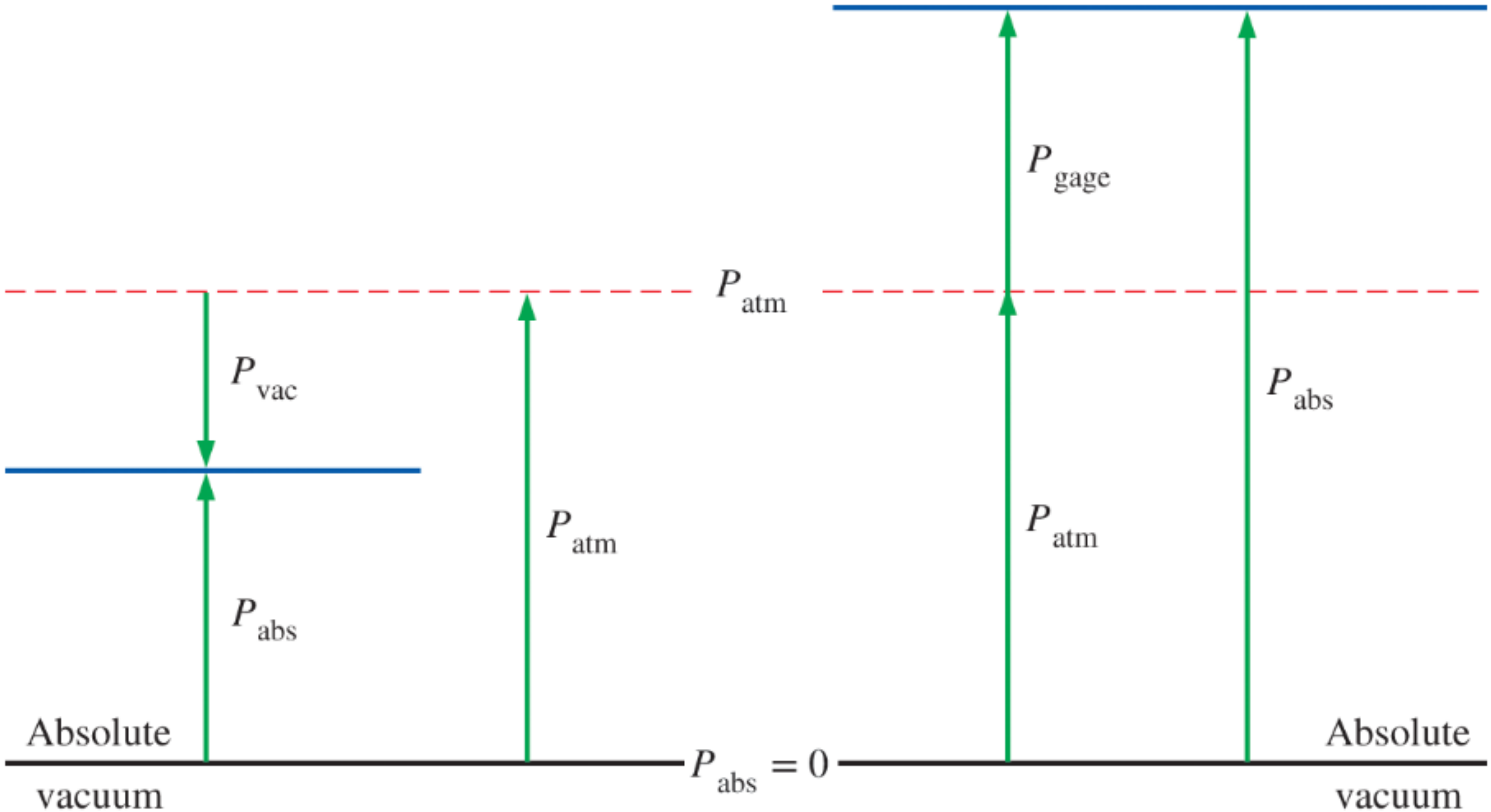
Pressure

- Actual pressure at a given position is called the absolute pressure (measured relative to absolute vacuum)
- The difference between the absolute pressure and the local atmosphere pressure is called the gage pressure
- Pressure below atmospheric pressure is called vacuum

Pressure


P_{gage}
P_{atm}
P_{vac}
P_{abs}
P_{atm}
P_{atm}
P_{abs}
P_{abs}
Absolute
vacuum
$P_{abs} = 0$
Absolute
vacuum

CLASS ACTIVITY

Class Activity

- A vacuum gage connected to a chamber reads 5.8 psi at a location where the atmospheric pressure is 14.5 psi. Determine the absolute pressure in the chamber

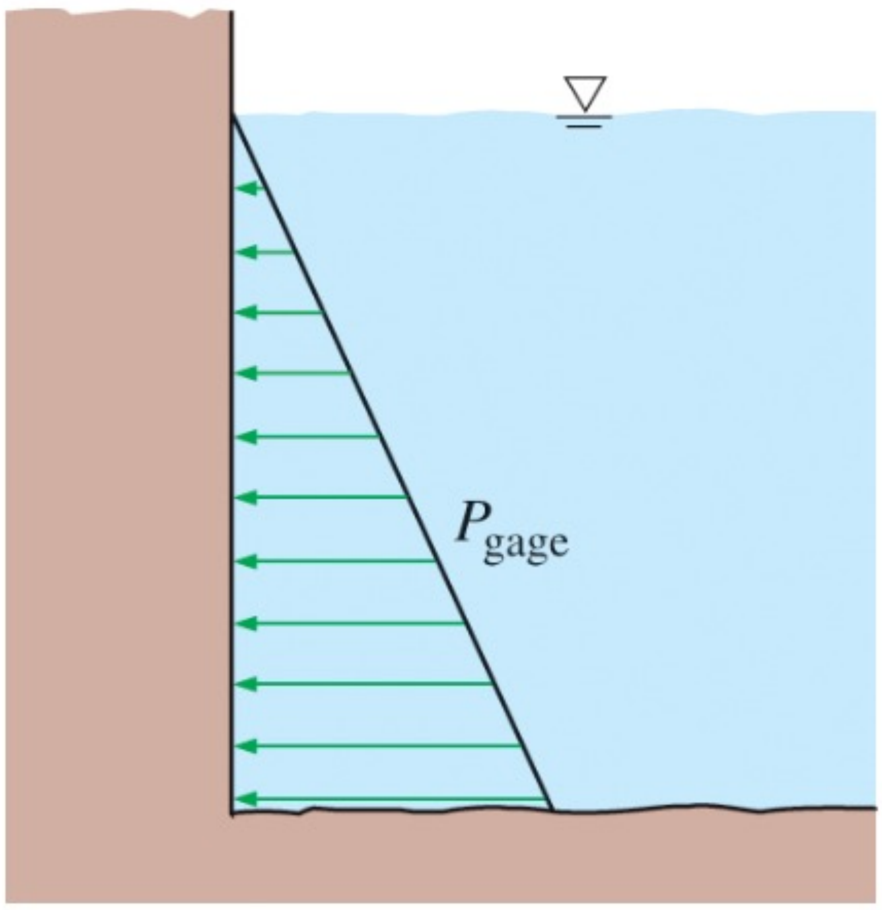
CLASS ACTIVITY

Class Activity

- The hydraulic piston/cylinder system has a cylinder diameter of D = 0.1 m with a piston and rod mass of 25 kg. The rod has a diameter of 0.01 m with an outside atmospheric pressure of 101 kPa. The inside hydraulic fluid pressure is 250 kPa. How large a force can the rod push with in the upward direction?

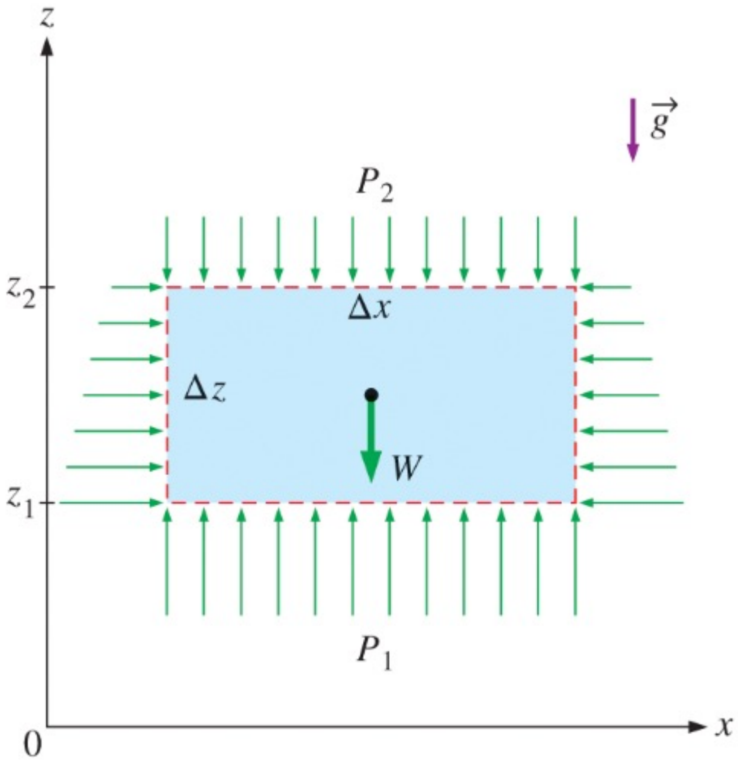
Pressure

- Variation of pressure with depth is due to the gravity field



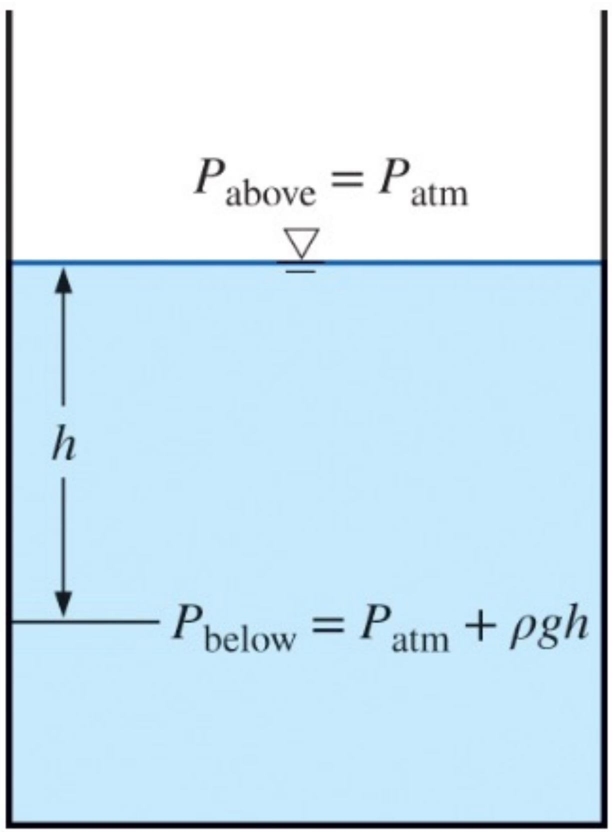
Pressure

- Pressure in a static fluid increases linearly with depth



Pressure

- We define P_{above} and P_{below}



Pressure

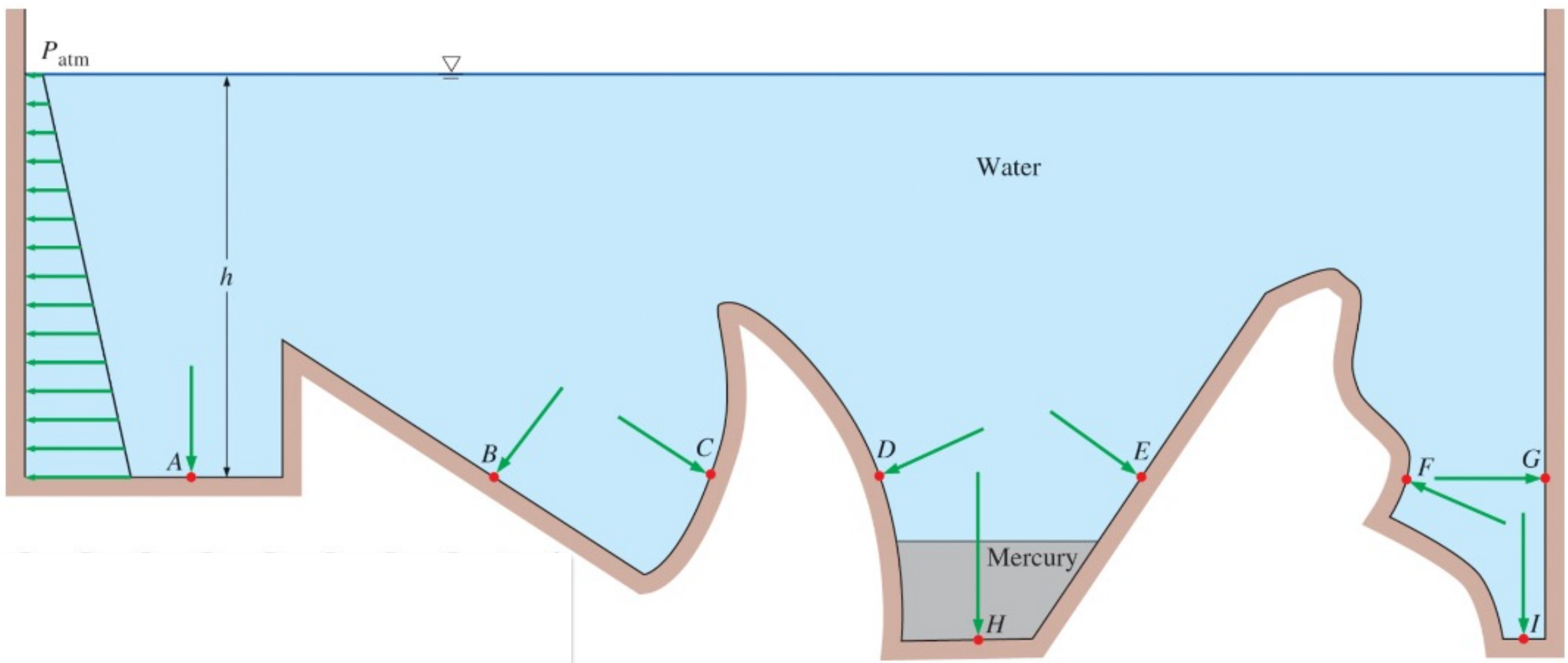
- ”g” varies from 9.807 m/s^2 at the sea level to 9.764 m/s^2 at an elevation of 14,000 m (0.4% in the extreme)

$$\frac{dP}{dz} = -\rho g$$

$$\Delta P = P_2 - P_1 = -\int_1^2 \rho g dz$$

Pressure

- Let's look at this example:



Pressure

- Pascal's law: The pressure applied to a confined fluid increases the pressure throughout the same amount