Lecture 23

Goals:

• Chapters 16 and 17, thermodynamics

Assignment

• HW-9 due Tuesday, Nov 23
• Wednesday: Read through Chapter 18.2
• Third test on Thursday, December 2

Temperature

• Three main scales

<table>
<thead>
<tr>
<th>Fahrenheit</th>
<th>Celsius</th>
<th>Kelvin</th>
</tr>
</thead>
<tbody>
<tr>
<td>212</td>
<td>100</td>
<td>373.15</td>
</tr>
<tr>
<td>32</td>
<td>0</td>
<td>273.15</td>
</tr>
<tr>
<td>-459.67</td>
<td>-273.15</td>
<td>0</td>
</tr>
</tbody>
</table>

- Water boils
- Water freezes
- Absolute Zero
Phase-diagrams

- Recall “3” Phases of matter: Solid, liquid & gas
- All 3 phases exist at different $p,T$ conditions

- Triple point of water:
  $p = 0.06 \text{ atm}$
  $T = 0.01^\circ \text{C}$

- Triple point of CO$_2$:
  $p = 5 \text{ atm}$
  $T = -56^\circ \text{C}$

Ideal Gas Law

- Assumptions that we will make:
  - “hard sphere” model for the atoms
  - density is low
  - temperature not too high

\[
P \, V = n \, R \, T
\]

$n$: # of moles
$R=8.31 \text{ J/mol K}: \text{universal gas constant}$
Suppose that we have a sealed container at a fixed temperature. If the volume of the container is doubled, what would happen to pressure?

A) Double  
B) Remain the same  
C) Halved  
D) None of the above

\[ PV = nRT \]

\[ PV = \text{constant if } n, T \text{ fixed} \]

**Boltzmann’s constant**

\[ PV = nRT \]

\[ n: \# \text{ of moles} \]
\[ n = \frac{N}{N_A} \]

\[ PV = nRT = \left(\frac{N}{N_A}\right)RT \]
\[ = N \left(\frac{R}{N_A}\right)T \]

\[ PV = N k_B T \]

\[ k_B: \text{Boltzmann’s constant} \]
PV diagrams: Important processes

- Isochoric process: $V = \text{const}$ (aka isovolumetric)
- Isobaric process: $P = \text{const}$
- Isothermal process: $T = \text{const}$
● Which one of the following PV diagrams describe an isobaric process (P=constant)

A) \[ V \text{ constant, isochoric} \]

B) \[ PV \text{ constant, isothermal} \]

C) \[ P \text{ constant, isobaric} \]

---

**Work done on a gas**

\[ \Delta W = F_{\text{ext}} \Delta x = P A \Delta x = P \Delta V \]

\[ \Delta V = V_{\text{final}} - V_{\text{initial}} \]

\[ \Delta W = -P \Delta V \]
Work done on a gas

\[ \Delta W = -P \Delta V \]

\[ W = \text{the area under the } P-V \text{ curve} \]

\[ W = \text{the area under the } F-x \text{ curve} \]

- For an isochoric process \((V=\text{const})\), \(W=0\)
How does the work done on the gas compare for the below two processes?

A) $|W_1| > |W_2|$  
B) $|W_1| = |W_2|$  
C) $|W_1| < |W_2|$

**Work and Energy Transfer**

When you do work on a system, the energy of the system increases:

- Potential Energy ($\Delta U$)
- Kinetic Energy ($\Delta K$)
- Thermal Energy ($\Delta E_{\text{thermal}}$)

\[
\Delta U + \Delta K + \Delta E_{\text{thermal}} = \Delta E_{\text{system}} = W_{\text{external}}
\]
• This description is incomplete. Energy can be transferred without doing any work.

Q: Thermal energy transfer

\[ \Delta U + \Delta K + \Delta E_{\text{thermal}} = \Delta E_{\text{system}} = W_{\text{external}} + Q \]

Q>0, environment is at a higher temperature
Q<0, environment is at a lower temperature

First Law of Thermodynamics

\[ \Delta U + \Delta K + \Delta E_{\text{thermal}} = \Delta E_{\text{system}} = W_{\text{external}} + Q \]

• For systems where there is no change in mechanical energy:

\[ \Delta E_{\text{thermal}} = W_{\text{external}} + Q \]
Heat to system, $Q > 0$

Work on system, $W > 0$

Work by system, $W < 0$

Energy in

Energy out

Heat from system, $Q < 0$