• C10 – Thermal Energy
• C11 – Energy in Bonds
Disappearing Energy

- Contact friction interaction doesn’t change potential energy because the separation between the two objects doesn’t change.
- Kinetic energy of object decreases, but where does the energy go?
Thermal Energy

- All objects are constructed of a huge number of tiny molecules
- These molecules are in ceaseless random motion
- An object’s temperature is a measure of the intensity of motion

\[ K_{avg} = \frac{1}{2} mv^2 = \frac{3}{2} k_B T \]

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Friction and Thermal Energy

- When a surface moves past another other, their surface molecules often become entangled.
- The entangled molecules are stretched away from their normal positions.
- A small amount of kinetic energy is transformed to potential energy in the bonds between the molecules.
- When the molecules snap back, they oscillate.
- The energy is transmitted to the rest of the molecules in the objects.

![Diagram of molecules](image1)

![Diagram showing movement and energy transfer](image2)

![Diagram showing oscillation and energy release](image3)
Heat and Work

- Heat and work are defined to describe energy transfer across a system boundary.
- Heat is any energy that crosses the boundary between two objects because of the temperature difference between them.
- Work is any other kind of energy flowing across an object’s boundary.
- The change in internal energy of an object is the heat added to and the work flowing into the system.

\[ \Delta U = Q + W \]
Specific Heat

- A small change in an object’s thermal energy is proportional to the mass, the specific heat, and the temperature change

\[ dU_{th} = McdT \]

**Table C10.1** Specific “heats” of some common substances (evaluated at ≈20 °C)

<table>
<thead>
<tr>
<th>Substance</th>
<th>Specific “Heat” (J·kg(^{-1}·K^{-1}))</th>
<th>Substance</th>
<th>Specific “Heat” (J·kg(^{-1}·K^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>4186</td>
<td>Air</td>
<td>≈ 740</td>
</tr>
<tr>
<td>Alcohol</td>
<td>2400</td>
<td>Iron</td>
<td>450</td>
</tr>
<tr>
<td>Ice (−5 °C)</td>
<td>2100</td>
<td>Copper</td>
<td>387</td>
</tr>
<tr>
<td>Wood</td>
<td>≈ 1700</td>
<td>Silver</td>
<td>234</td>
</tr>
<tr>
<td>Aluminum</td>
<td>900</td>
<td>Gold</td>
<td>129</td>
</tr>
<tr>
<td>Granite</td>
<td>790</td>
<td>Lead</td>
<td>128</td>
</tr>
</tbody>
</table>
Problem Imagine that we drop a bag of lead shot (small lead spheres) from rest at the top of a 10-story building. When the bag of shot hits the ground, almost all its kinetic energy of motion will go to banging the lead spheres against each other inside the bag, and thus eventually to thermal energy in the lead (very little thermal energy gets deposited in the ground). If this model is accurate, about how much warmer should the lead shot be after it hits the ground?

Translation

\[
0 = \Delta K_b + \Delta K_c + \Delta V + \Delta U_b^{th} + \Delta U_s^{th}
\]

\[
= \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2 + 0 + \frac{\eta g (z_f - z_i)}{2} + \eta g \Delta T + 0
\]

Earth is very massive

Bag remains near the earth's surface

Given

Assume that \( \Delta T \) is sufficiently small, and ignore parts of the bag that are not lead
Imagine that we place a 50-g block of aluminum with an initial temperature of 100°C into an insulating covered Styrofoam cup containing 250 g of water at 22°C. Heat will flow from the aluminum to the water until both are at the same temperature. What is that temperature?
Potential Energy Diagrams

- $F = -\frac{dV}{dx}$
- Stable/unstable equilibrium
- Turning points: $E = V(x)$
- Forbidden regions: $E < V(x)$
- Allowed regions: $E > V(x)$

Figure C11.1
Examples of potential energy diagrams.
Bonds

- Typical potential energy curve for a bond.
- When bonds form, energy is released.
- When bonds break, energy is absorbed.

**Figure C11.3**
(a) Graph of a possible potential energy function for a system of two interacting atoms. (b) The system’s forbidden regions when $E = E_2$. 
Latent Heat

\[ \Delta U_{th} = +mL \quad \Delta U_{la} = -mL \]

\[ \Delta U_{th} = -mL \quad \Delta U_{la} = +mL \]

For condensation or freezing
For vaporization or melting

L is the latent heat, m is the mass

The latent heat is the energy a substance absorbs or releases per kilogram during a change of phase.

<table>
<thead>
<tr>
<th>Substance and Phase</th>
<th>Latent &quot;Heat&quot; (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting O₂</td>
<td>13.8</td>
</tr>
<tr>
<td>Melting H₂</td>
<td>58.6</td>
</tr>
<tr>
<td>Melting Al</td>
<td>105</td>
</tr>
<tr>
<td>Melting Cu</td>
<td>205</td>
</tr>
<tr>
<td>Melting H₂O</td>
<td>333</td>
</tr>
<tr>
<td>Boiling O₂</td>
<td>213</td>
</tr>
<tr>
<td>Boiling H₂</td>
<td>452</td>
</tr>
<tr>
<td>Boiling H₂O</td>
<td>2,256</td>
</tr>
<tr>
<td>Boiling Cu</td>
<td>4,730</td>
</tr>
<tr>
<td>Boiling Al</td>
<td>11,400</td>
</tr>
</tbody>
</table>
Group Problems

- C10S.1
- C10S.2
- C11S.5
- C11S.11