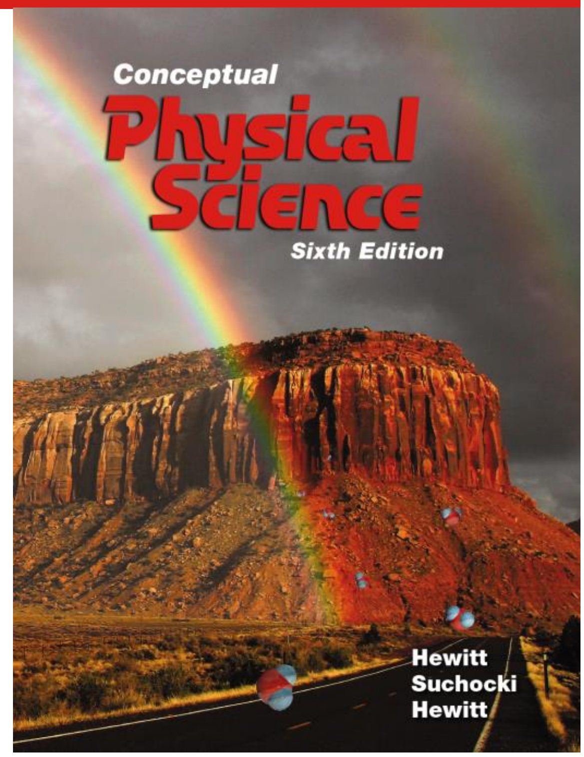
Chapter 6 Lecture



Chapter 6: Thermal Energy and Thermodynamics

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Temperature

- Temperature
  - A number that corresponds to the warmth or coldness of an object
  - Measured by a thermometer
  - No upper limit
  - Definite limit on lower end

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Temperature

- In a substance, particles are always moving.
- When you heat a substance, its molecules move faster.
- When molecules move faster, the substance gets hotter.
- When a substance gets hotter, its temperature goes up.
- Temperature is proportional to the average translational kinetic energy per particle in a substance.

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Temperature

- Thermometer
  - Measures temperature by expansion or contraction of a liquid (mercury or colored alcohol)
  - Reading occurs when the thermometer and the object reach thermal equilibrium (having the same average kinetic energy per particle)
  - Infrared thermometers operate by sensing IR radiation

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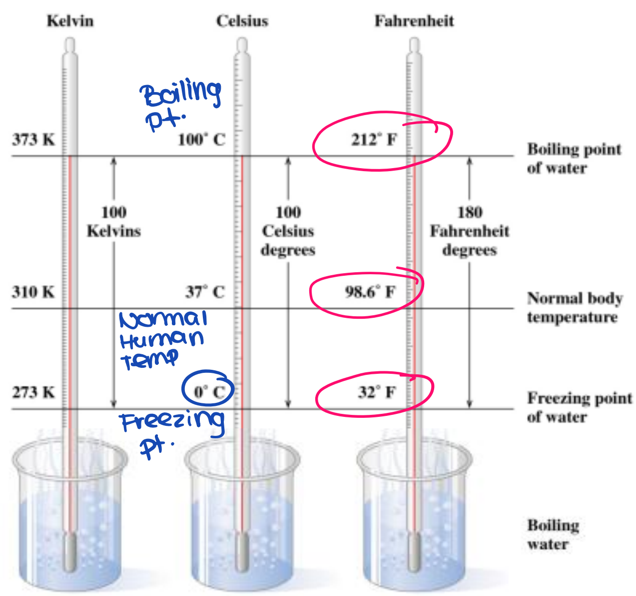
Temperature

Temperature Scales

- There are three different temperature scales

1. Celsius scale.
2. Fahrenheit scale.
3. Kelvin scale.



$T_K = T_C + 273$ (kelvin scale)

Ex

$T_{K\,normal\,temp} = 37 + 273$

$T_{K\,Freezing} = 0 + 273$

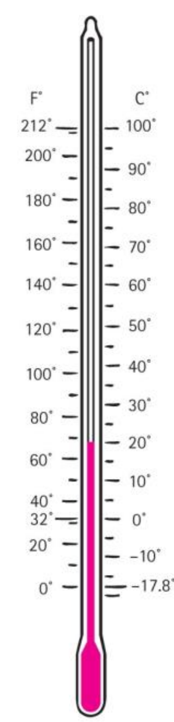
$T_{K\,boiling} = 100 + 273$

Temperature

Temperature Scales

⋆

- **Celsius scale :**
  - 0 °C for the freezing point of water to 100 °C for the boiling point of water (100 divisions)
- **Fahrenheit scale:**
  - 32 °F for the freezing point of water to 212 °F for the boiling point of water (180 divisions)
  - Note that a change in temperature of 1°C corresponds to a change of 1.8 °F
- **Kelvin scale:**
  - 273 K for the freezing point of water to 373 for the boiling point of water. (100 divisions)



Temperature

- What is the difference between Temperature and Thermal Energy?
  - Thermal energy is the total sum of kinetic energy of all the particles in a container, while Temperature is proportional to the average KE per particle.
- For example, if you have a cup of hot water and poured half of it on the floor, the water remained in the cup hasn't changed it's temperature, while the new thermal energy is half the original one.

Temperature
CHECK YOUR NEIGHBOR

There is twice as much molecular kinetic energy in 2 liters of boiling water as in 1 liter of boiling water. Which will be the same for both?

A. Temperature.
B. Thermal energy.
C. Both of the above.
D. None of the above.

Temperature
CHECK YOUR ANSWER

There is twice as much molecular kinetic energy in 2 liters of boiling water as in 1 liter of boiling water. Which will be the same for both?

A. Temperature.

B. Thermal energy.

C. Both of the above.

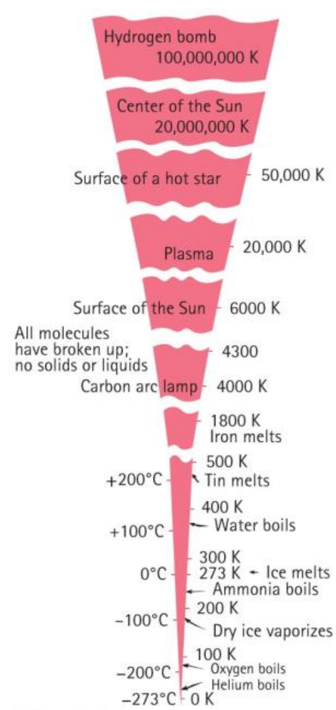
D. None of the above.

Explanation:

Average kinetic energy of molecules is the same, which means temperature is the same for both.

Absolute Zero

- Absolute zero, or 0 K,
  - is the ***lowest limit of temperature*** at –273ºC. At this temperature, atoms or molecules have lost all available kinetic energy. A substance cannot get any colder.
  - The pressure of a gas in a fixed container will be also zero at absolute zero temperature.



What Is Heat?

- Heat
  - defined as a *flow of thermal energy* due to a temperature difference.
  - natural direction of heat flow is from a higher-temperature substance to a lower-temperature substance (not from higher thermal energy to lower thermal energy!).
  - A substance doesn't contain heat, it contains thermal energy.

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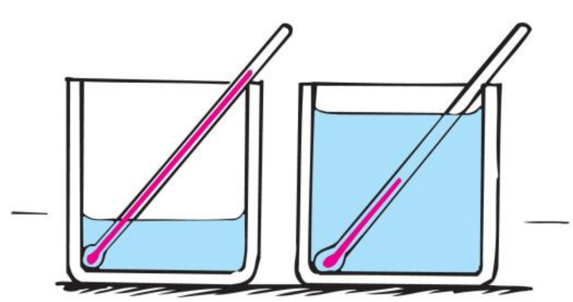
Heat

- 1 liter of water in left pot versus 3 liters in right pot.
- both pots absorb the same quantity of heat
- temperature increases three times as much in the pot with the smaller amount of water.



Hot stove

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Heat

- You apply a flame to 1 L of water for a certain time and its temperature rises by 2^0 C . If you apply the same flame for the same time to 2 L of water. By how much does its temperature rise?

1 °C

Quantity of Heat

- Heat is energy in transit, measured in units of energy—joules or calories.
- **calorie**
  - defined as the amount of heat needed to raise the temperature of 1 gram of water by 1 Celsius degree.
  - 4.19 joules = 1 calorie
  - so 4.19 joules of heat will change that temperature of 1 gram of water by 1 Celsius degree.

kcal amount of heat needed to raise temp 1kg of water by 1°C

1 calorie = 4.19 J

1 c = 4.19 J

1 kcalorie = 1000 calories

1 C = 1000 × 4.19 = 4190 J

10 C = 10 × 1000 × 4.19 = 41900 J

Quantity of Heat

- Energy rating of food is measured by energy released from the food when metabolized
- Kilocalorie
  - heat unit in labeling food
  - One kilocalorie or Calorie (with a capital C) is the heat needed to change the temperature of 1 kilogram of water by 1 degree Celsius.

Quantity of Heat

- 1 food Calorie equals 1000 calories. To the weight watcher, the peanut contains 10 Calories.
- To the scientist, the peanut releases 10,000 calories (41,900 joules) of energy when burned or digested.

Quantity of Heat
CHECK YOUR NEIGHBOR

You heat a half-cup of tea and its temperature rises by 8ºC. How much will the temperature rise if you add the same amount of heat to a full cup of tea?

A. 0ºC.
B. 2ºC.
C. 4ºC.
D. 8ºC.

Quantity of Heat
CHECK YOUR ANSWER

You heat a half-cup of tea and its temperature rises by 8ºC. How much will the temperature rise if you add the same amount of heat to a full cup of tea?

A. 0ºC.
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C. 4ºC.
D. 8ºC.

Quantity of Heat

1c = 4.19 J
c = $\frac{4.19}{4.19}$ = $\frac{350}{4.19}$

- How many joules are there in 170 calorie?

1c = 4.19 J

4.19 × 170 Joules

712.3 J

- How many calories are there in 350 joules?

$\frac{350}{4.19}$ calories

83.5 calories

Specific Heat Capacity

Some things heat up or cool down faster than others.

Specific Heat Capacity

- Definition: Specific heat capacity is the amount of heat required to raise the temperature of 1 kg of a material by one degree (°C or K).
- The formula that relates the quantity of heat (Q) with the specific heat capacity (C) is

$$Q = m\,c\,\Delta T$$

  - Q = amount of in thermal energy needed (in J)
  - m = mass of the substance (in kg)
  - c = specific heat capacity of the substance (J/kg.°C)
  - ΔT = change in temperature ($T_f - T_i$) (in °C or K)°

→kg by 1C°

is the same

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Specific Heat Capacity

- The small values show that small amount of thermal energy is needed to produce a temperature change, whereas the large values indicate that a lot more energy is needed.
- Question: Why water is used in cooling the engines?

Material	Specific heat capacity ($Jkg^{-1}K^{-1}$)
Air	100
Lead	130
Copper	390
Iron	450
Oil	540
Aluminium	899
Concrete	900 ≈1000
Water	4200 ≈4000

takes a while to heat up

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$$Q = mc\Delta T$$

Q → J, m → kg

$$\Delta T = T_f - T_i$$

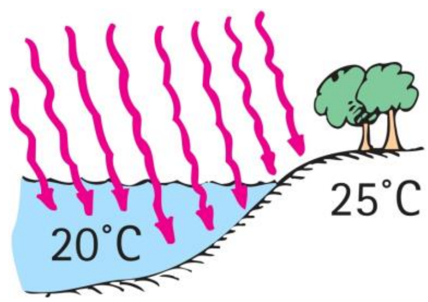
$\frac{C^\circ \text{ or } K}{\text{same}}$

$$T_K = T_C + 273$$

$$c = \frac{Q}{m\Delta T} = \frac{J}{kg \cdot C^\circ}$$

Specific Heat Capacity

- land heats up quickly during the day and cools quickly at night, while water takes longer time to change temperature because of the big difference between their specific heat capacity.
  - C_{water} = 4184 J / kg.°C
  - C_{sand} = 664 J / kg.°C



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Examples

$m = 450 \div 1000 = 0.45 \text{ kg}$

- How much thermal energy is needed to heat 450 g of copper metal from a temperature of 25 ºC to a temperature of 75 ºC? Given the specific heat of copper is 390 J/(kg.ºC)

$\Delta T = T_f - T_i = 75 - 25 = 50°C$

$Q = mc\Delta T$

$Q = (0.45)(390)(50) = 8775 \text{ J}$

- If 216 J of energy is required to raise the temperature of an aluminum block from 15 °C to 35 °C. Calculate the mass of the aluminum block, given the specific heat capacity of aluminum is 900 J/(kg.°C).

$\Delta T = 20°C$
$Q = 216$
$m = ?$
$c = 900 \text{ J/kg.°C}$

$Q = mc\Delta T$

$216 = m \cdot 900 \cdot 20$

$216 = m \cdot 18000$

$m = 0.012 \text{ kg}$

$c = \frac{Q}{m\Delta T}$

$\frac{900}{1} = \frac{216}{m \cdot 20}$

$900 m \cdot 20 = 216$

$18000 m = 216$

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18000 18000

m=

Examples

- Determine the final temperature when a 25 g piece of iron at 85 °C is placed into 75 g of water at 20 °C. The specific heat of iron is 450 J/(kg.°C) and the specific heat of water is 4180 J/(kg.°C).

$$-Q_{lost\ (iron)} = Q_{gained\ (water)}$$

$$-m_{iron}\, c_{iron} ((T_f - T_i)_{iron}) = m_{water}\, c_{water} ((T_f - T_i)_{water})$$

$$-0.025 \cdot 450 \cdot (T_f - 85) = 0.075 \cdot 4180 (T_f - 20)$$

$$T_f = 22.25 C°$$

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