Module 2: Energy, Heat, and Temperature

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1 Overview

1. **Energy** is the ability to do work
2. **Heat** is thermal energy flowing into a system
3. **Temperature** is a measure of the average thermal energy of a system

2 Heat, Energy, and Temperature

- energy is the ability to do work
- work done on a system can move it, speed it up, slow it down, or transform it
    1. we generally think of work as the force applied to an object times the distance the object is moved by that force ($W = F \cdot d$) [1]
- **Heat** is energy transferred as a result of temperature differences
- **Temperature** is the average thermal energy of a system

3 The Nature of Scientific Laws

- science is an *inductive* process: it involves observation, measurement, and experimentation
- in general terms, the scientific process moves through several stages:
    1. observation
    2. hypothesis

[1] OK, ok, …it's something more like: $W = \vec{F} \cdot \vec{d}$. It would be even more accurate to say something like $W = \int_c \vec{F} \cdot d\vec{x}$, but we're still in high school here.

3. experimentation
4. theory
5. repeated confirmation
6. scientific law

- in principle, even a scientific law is open to refutation with careful observation, experimentation, and theory
- it's surprisingly easy to "walk off the map" in scientific endeavors

4 The First Law of Thermodynamics

Law 1 (The First Law of Thermodynamics) *Energy cannot be created or destroyed. It can only change form.*

- this is "The Law of Conservation of Energy"
- we can move energy from place to place, or from form to form, but we can't actually make more
- the two most basic forms of energy are:
  1. Potential Energy: energy that is stored
  2. Kinetic Energy: energy that is in motion
- we can think of chemical energy as a form of potential energy: it's energy stored in chemical bonds
- we can think of energy stored in a battery as potential energy
- we can think of energy stored in a spring as potential energy
- heat is a form of kinetic energy: it's energy moving into (or out of) a system

5 Measuring Heat and Energy

- we measure mechanical energy in *Joules (J)* in the metric system
- the explanation of a Joule here is pretty convoluted, let's use: $1J = \frac{1kg \times 1m^2}{1s^2}$

5.1 Temperature Scales

- there are four main temperature scales we use:

1. the Fahrenheit scale ($^\circ F$)
2. the Rankine scale
3. the Celsius scale ($^\circ C$)
4. the Kelvin scale

- the last two are what we'll use in the metric system
- at *standard pressure*, water freezes at $32^\circ F$ or $0^\circ C$
- at *standard pressure*, water boils at $212^\circ F$ or $100^\circ C$
- (at what temperature does water boil in Moscow?)

5.1.1 Converting between Fahrenheit and Celsius

- we can convert between temperatures in Fahrenheit and temperatures in Celsius with some Algebra I:
  1. hint: this is a *linear* relationship
  2. we already have two points, so we can define a line: $(32^\circ F, 0^\circ C)$ and $(212^\circ F, 100^\circ C)$
  3. we know that $y = mx + b$
  4. we know that $m = \frac{y_1 - y_0}{x_1 - x_0}$
  5. so let's apply that to our current problem:

$$\boxed{\begin{aligned} m &= \frac{T_{C1} - T_{C0}}{T_{F1} - T_{F0}} \\ &= \frac{100^\circ C - 0^\circ C}{212^\circ F - 32^\circ F} \\ &= \frac{100^\circ C}{180^\circ F} \\ &= \frac{5^\circ C}{9^\circ F} \end{aligned}} \tag{1}$$

  6. and:

$$\boxed{\begin{aligned} T_C &= mT_F + b \\ T_C - mT_F &= b \\ b &= T_C - mT_F \end{aligned}} \tag{2}$$

7. so:

$$\boxed{\begin{aligned} b &= T_{C0} - (m)(T_{F0}) \\ &= (0°C) - (\frac{5°C}{9°F})(32°F) \\ &= -\frac{(32°F)(5°C)}{9°F} \\ &= -\frac{160}{9}°C \end{aligned}} \tag{3}$$

8. which gives us: $T_C = (\frac{5°C}{9°F})T_F - \frac{160}{9}°C$

- and that's super ugly... we can just use: $T_C = (\frac{5}{9})(T_F - 32°F)$ [Wile, 2003, p. 45]
- and please, *please* don't conflate units of measure with variables, like they do in the book![2]
- conversely, we can convert Celsius measurements to Fahrenheit with: $T_F = (\frac{9}{5})T_C + 32°F$ [Wile, 2003, p. 46]

5.1.2 Kelvin and Rankine Scales

- Kelvin and Rankine scales are *absolute* temperature scales: there are no negative temperatures
- to convert between Celsius and Kelvin scales, just add 273.15 K: $T_K = T_C + 273.15K$ [Wile, 2003, p. 46]
- similarly, to convert between Fahrenheit and Rankine scales, just add $459.67°R$: $T_R = T_F + 459.67°R$
- Rankine is *not* in our book, but I want you to be aware there is an analog to Kelvin for the English system

[2] In a just society, the penalty of this would make our ears tingle to hear of it. I cannot be made to believe it won't come up in the Final Judgment on the Last Day.

5.2 Examples

Example 1 The highest temperature Mr. Peever can remember from when he was living in St. Louis is $116°F$. What is that temperature in the Celsius scale?

$$\boxed{\begin{aligned}T_C &= (\frac{5°C}{9°F})(T_F - 32°F) \\ &= (\frac{5°C}{9°F})(116°F - 32°F) \\ &= (\frac{5°C}{9°F})(84°F) \\ &= (\frac{5°C}{9\cancel{°F}})(84\cancel{°F}) \\ &= \frac{420°C}{9} \\ &= 46.666667°C \\ &= 46.7°C\end{aligned}} \tag{4}$$

Example 2 The lowest temperature Mr. Peever can remember from when he was living in Canada is $-45°C$. What is that temperature in the Fahrenheit scale?

$$\boxed{\begin{aligned}T_F &= (\frac{9°F}{5°C})T_C + 32°F \\ &= (\frac{9°F}{5°C})(-45°C) + 32°F \\ &= (\frac{9°F}{5\cancel{°C}})(-45\cancel{°C}) + 32°F \\ &= (\frac{9°F}{1})(-9) + 32°F \\ &= -81°F + 32°F \\ &= -49°F\end{aligned}} \tag{5}$$

Example 3 What is Mr. Peever's lowest temperature in the Kelvin scale?

$$\boxed{\begin{aligned}T_K &= T_C + 273.15K \\ &= -45°C + 273.15K \\ &= (-45°C)(\frac{1K}{1°C}) + 273.15K \\ &= (-45\cancel{°C})(\frac{1K}{1\cancel{°C}}) + 273.15K \\ &= -45K + 273.15K \\ &= 228.15K\end{aligned}} \tag{6}$$

6 Calorie, calories, and kilocalories

- Heat is energy, but... we generally measure heat in *calories*[3]
- 1 calorie is the amount of heat necessary to raise the temperature of $1g$ of water by $1°C$
- since both calories and Joules measure energy, we ought to be able to convert between them: $1calorie = 4.184Joules$ [Wile, 2003, p. 48]
- in the world of nutrition, we measure energy in *kilocalories* ($1kcal = 1000cal$)
- oddly, we generally write kilocalories as "Calories": $1Cal = 1kcal = 1000cal$)

7 Measuring Heat

- remember that heat is thermal energy moving in (or out) of a system
- we can calculate heat as: $q = mc\Delta T$
- generally, the Delta symbol(Δ) indicates a change, so ΔT is a change in temperature: $\Delta T = T_{final} - T_{initial}$
- (note: we could also write that as $\Delta T = T_2 - T_1$, or even as $\Delta T = T_1 - T_0$)[4]
- so back to our heat equation...
  1. q is heat
  2. m is the *mass* of our object (generally in grams)
  3. c is the *specific heat* of our object (generally in $\frac{J}{g \cdot °C}$)
  4. ΔT is the change in temperature of our object (generally in $°C$, but K would work too)

[3] Because of course we do.
[4] This last is the Physics way to Chemistry.

7.1 Examples

Example 1 What is the specific heat of water?

$$\boxed{\begin{aligned} q &= mc\Delta T \\ \frac{q}{c} &= m\Delta T \\ \frac{1}{c} &= \frac{m\Delta T}{q} \\ (\frac{1}{c})^{-1} &= (\frac{m\Delta T}{q})^{-1} \\ c &= \frac{q}{m\Delta T} \\ &= \frac{1cal}{1g \cdot 1°C} \\ &= \frac{1cal}{1g \cdot 1°C} \\ &= 1\frac{cal}{g \cdot ^\circ C} \end{aligned}} \tag{7}$$

Example 2 What is the specific heat of water in Joules?

$$\boxed{\begin{aligned} c &= 1\frac{cal}{g \cdot ^\circ C} \\ &= 1(\frac{cal}{g \cdot ^\circ C})(\frac{4.184J}{1cal}) \\ &= 1(\frac{\cancel{cal}}{g \cdot ^\circ C})(\frac{4.184J}{1\cancel{cal}}) \\ &= 1(\frac{4.184J}{g \cdot ^\circ C}) \\ &= 4.184\frac{J}{g \cdot ^\circ C} \end{aligned}} \tag{8}$$

8 Homework

Review Problems: p. 67 # 1–10
Practice Problems: p. 68 # 1–10 (due 2025-09-05)

References

[Wile, 2003] Wile, J. L. (2003). *Exploring Creation with Chemistry.* Apologia Educational Ministries, Inc., 2 edition.