Lecture 35

(Ch. 11: 1)

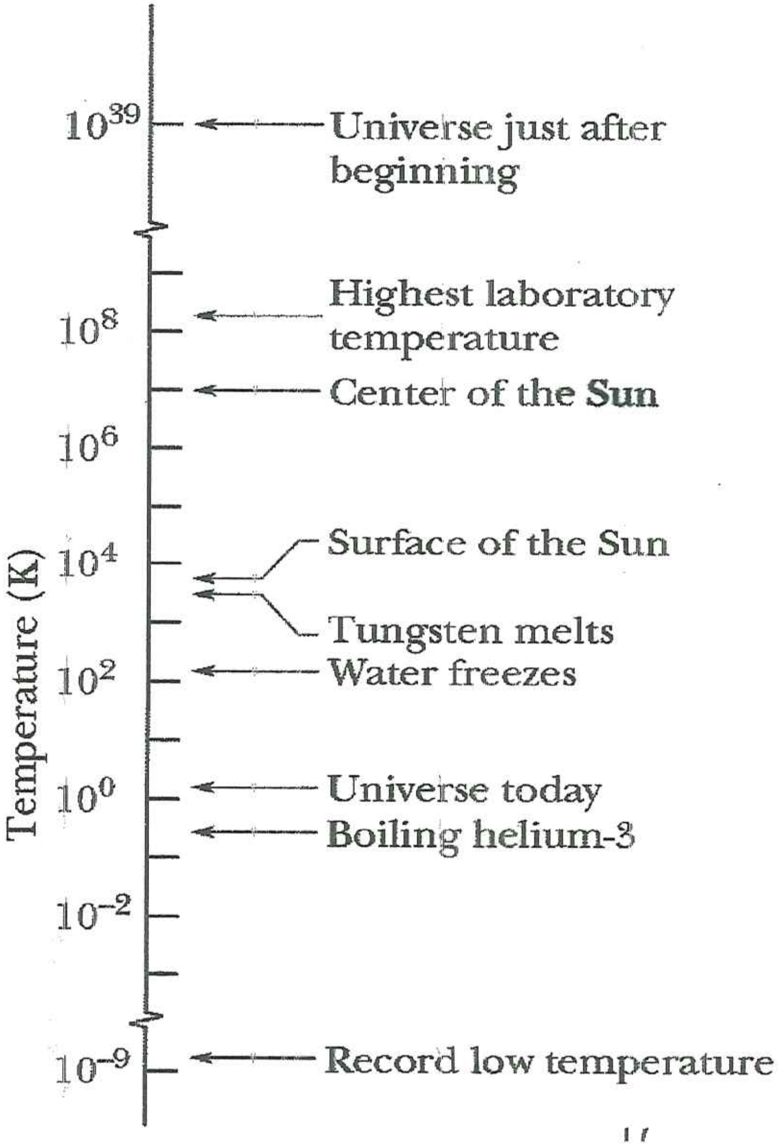
Thermodynamics & Temperature

- **Mechanics**: mechanical energy of systems governed by Newton's laws

- **Thermodynamics:** internal energy of bodies – *thermal energy*

- **Temperature**: central concept - sometimes a measure of the internal energy

  - Kelvin temperature - absolute temperature (see Fig 18-1)



Celsius and Fahrenheit Scales

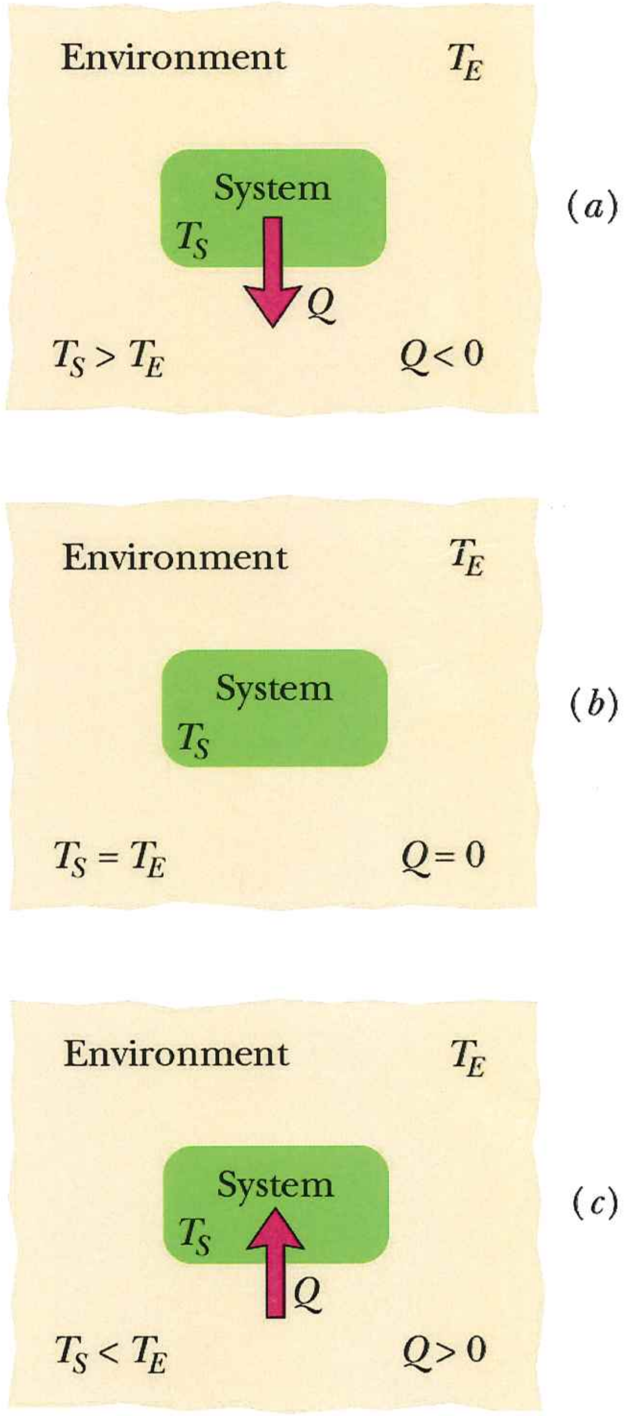
- Celsius scale: used worldwide

$$T_C = T - 273.15K$$ $\rightarrow$ $T[K] = T_C + 273.15$

  - 1° C = 1 K
  - 0° C => ice-water phase transition, normal pressure
  - 100° C => water-vapor phase transition
  - 37° C => normal human body temperature
  - 20° C => normal room temperature (68° F)

Temperature and Heat (Q)

- System vs Environment
- Change in temperature: transfer of internal energy, called ***heat***
- (see Fig 18-12 =>)
- ***Heat*** is the energy that is transferred between a system and its environment because of the temperature difference that exists between them



Heat and Internal Energy

Internal energy *U* is the energy associated with the atoms and molecules of the system.

Heat is the transfer of energy between a system and its environment due to a temperature difference between them.

Units of Heat

Calorie: the energy necessary to raise the temperature of 1 g of water from 14.5°C to 15.5°C.

$$1 \text{ cal} \equiv 4.186 \text{ J}$$

- **Units of heat (Q):**
  - – *calorie* (cal): heat 1 gram of water from 14.5° C to 15.5° C
  - – *British thermal unit* (Btu): heat 1 lb of water from 63° F to 64° F
  - – *Joule* (J): SI unit ; 1 cal = 4.186 J

1 cal = 3.969 x 10^{-3} Btu = 4.186 J

1 Food Calorie = 1,000 cal = 4186 J

1. Convert 3.50×10^3 cal to the equivalent number of

   a. kilocalories (also known as Calories, used to describe the energy content of food) and

   Answer ↓

   b. joules.

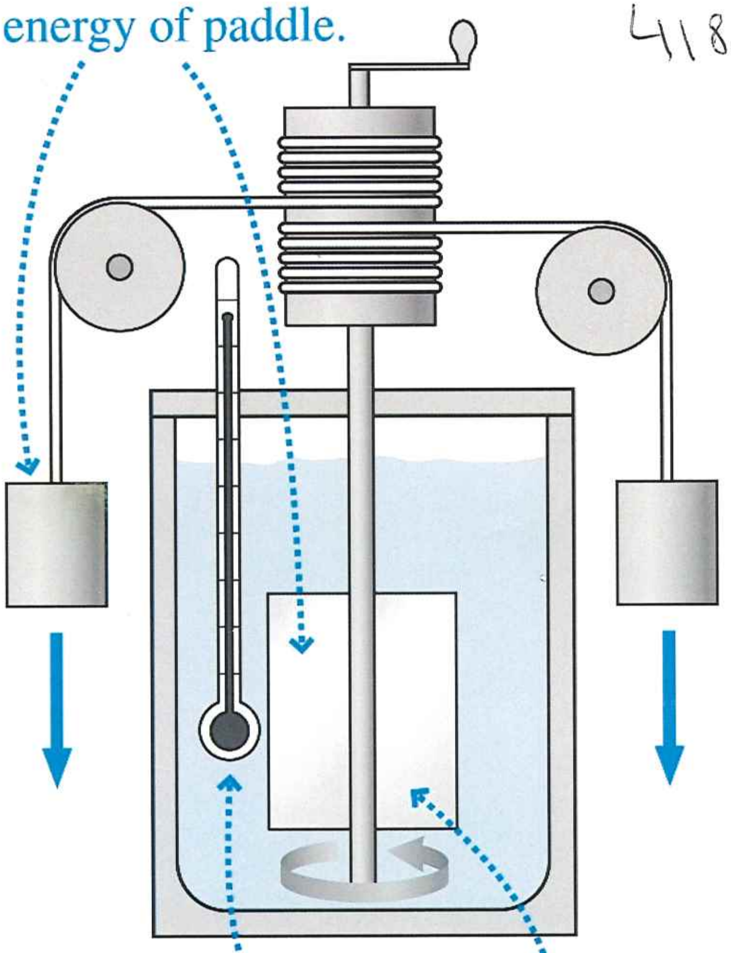
11.1 **(a)** 1 kcal = 1.00×10^3 cal so that $3.50 \times 10^3 \text{ cal} = \boxed{3.50 \text{ kcal}} = 3.50 \text{ Cal}$.

(b) Use the conversion 1 cal = 4.186 J to find

$$3.50 \times 10^3 \text{ cal} = 3.50 \times 10^3 \text{ cal}\left(\frac{4.186 \text{ J}}{1 \text{ cal}}\right) = \boxed{1.47 \times 10^4 \text{ J}}$$

Figure 13.1

Mechanical equivalent of heat



Potential energy of falling weights becomes kinetic energy of paddle.

The paddle's kinetic energy in turn becomes internal energy of the water, indicated by rising temperature.

4186 J raise 1 kg H_2O by 1°C

James Joule

; E = ? in Cal

23. SOLVE The change in gravitational potential energy is equal to:

$$U = mgh = (60\text{ kg})(9.80\text{ m/s}^2)(1200\text{ m}) = 706\text{ kJ}\left[\frac{1\text{ Cal}}{4186\text{ J}}\right] = 169\text{ Cal}$$

A 2000-kg car is going 55 mph. Find the thermal energy generated in the car's brakes when stopping the car.

Note 1 mph = (1609.3 m)/(60 min.60 sec) = 0.447 m/s

Therefore 55 mph = (0.447 m/s).(55) = 24.59 m/s

Moving car possesses Kinetic energy $K = (½).m.v^2 =$

$= (½).(2000\ \text{kg}).(24.59\ \text{m/s})^2 = 6.045 \times 10^5\ \text{J}$

When the car stops its kinetic energy transforms into thermal energy

So the thermal energy generated in the car's brakes is = 6.045×10^5 J

4. BIO A 55-kg student eats a 540-Calorie (540 kcal) jelly doughnut for breakfast.

   a. How many joules of energy are the equivalent of one jelly doughnut?

   b. How many stairs must the student climb to perform an amount of mechanical work equivalent to the food energy in one jelly doughnut? Assume the height of a single stair is 15 cm.

   c. If the human body is only 25% efficient in converting chemical energy to mechanical energy, how many stairs must the woman climb to work off her breakfast?

11.4 **(a)** $Q = 540\ \cancel{\text{Cal}}\left(\frac{10^3\ \cancel{\text{cal}}}{1\ \cancel{\text{Cal}}}\right)\left(\frac{4.186\ \text{J}}{1\ \cancel{\text{cal}}}\right) = \boxed{2.3\times10^6\ \text{J}}$

(b) The work done lifting her weight mg up one stair of height h is $W_1 = mgh$. Thus, the total work done in climbing N stairs is $W = Nmgh$, and we have $W = Nmgh = Q$ or

$$N = \frac{Q}{mgh} = \frac{2.3\times10^6\ \text{J}}{(55\ \text{kg})(9.80\ \text{m/s}^2)(0.15\ \text{m})} = \boxed{2.8\times10^4\ \text{stairs}}$$

(c) If only 25% of the energy from the donut goes into mechanical energy, we have

$$N = \frac{0.25\,Q}{mgh} = 0.25\left(\frac{Q}{mgh}\right) = 0.25(2.8\times10^4\ \text{stairs}) = \boxed{7.0\times10^3\ \text{stairs}}$$

Absorption of Heat

- **Heat Capacity**
  - capacity of a body to absorb heat
  - specific to one body

$$Q = C(T_f - T_i)$$

$$C = \frac{Q}{T_f - T_i}$$

  - Units: cal/K, Btu/K, J/K

A piece of metal absorbs 3.6 kJ of heat, increasing its temperature by 33 ^{o}C. What is its heat capacity ?

By definition $Q = C\Delta T$ so heat capacity $C=Q/\Delta T$

In our case $Q = 3.6$ kJ and $\Delta T = 33$ ^{o}C

Therefore $C = (3600 \text{ J})/(33\ ^{o}\text{C}) = 109.1 \text{ J}/^{o}\text{C}$

- **Specific Heat**
  - specific to units of mass

$$Q = c\,m(T_f - T_i)$$

$$c = \frac{Q}{m\Delta T} = \frac{Q}{m(T_f - T_i)}$$

  - specific heat of water (for other Table 18-3)

$$c(H_2O) \longrightarrow c_w = 1 cal/g \cdot K = 1 Btu/lb \cdot F = 4190 J/Kg \cdot K$$

Checkpoint 18-3

A certain amount of heat Q will warm 1 g of material A by 3° C and 1 g of material B by 4° C. Which material has the greatest specific heat?

Specific Heat

$$c \equiv \frac{Q}{m\Delta T} \quad \text{SI unit: J/kg} \cdot {}^\circ\text{C}$$

$$Q = mc\Delta T$$

Example:

$$m_{\text{water}} = 0.500\ \text{kg};\ \Delta T = 3.00^\circ\text{C}$$

$$Q = (0.500\ \text{kg})(4186\ \text{J/kg} \cdot \text{C})(3.00^\circ\text{C})$$

$$= 6.28 \times 10^3\ \text{J}$$

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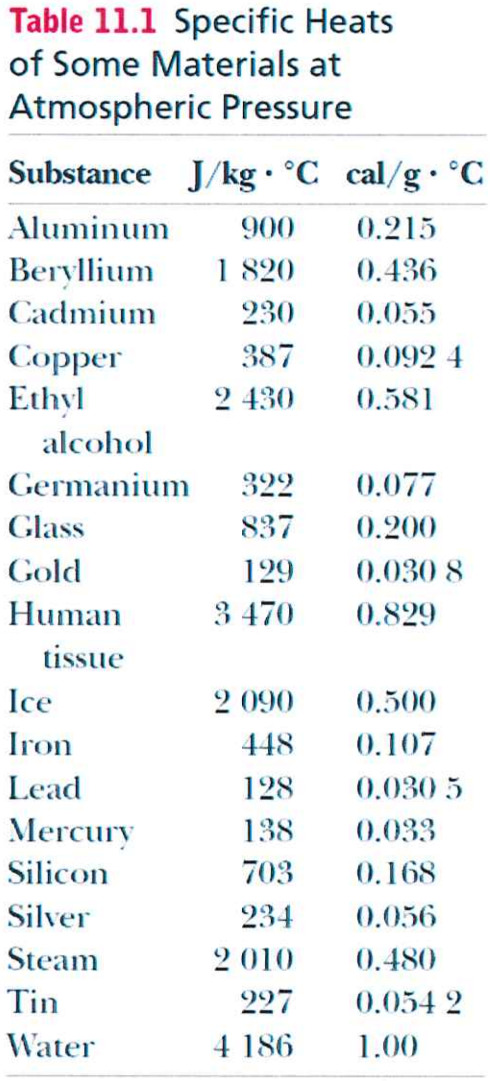


Table 11.1 Specific Heats of Some Materials at Atmospheric Pressure

Substance	J/kg · °C	cal/g · °C
Aluminum	900	0.215
Beryllium	1 820	0.436
Cadmium	230	0.055
Copper	387	0.092 4
Ethyl alcohol	2 430	0.581
Germanium	322	0.077
Glass	837	0.200
Gold	129	0.030 8
Human tissue	3 470	0.829
Ice	2 090	0.500
Iron	448	0.107
Lead	128	0.030 5
Mercury	138	0.033
Silicon	703	0.168
Silver	234	0.056
Steam	2 010	0.480
Tin	227	0.054 2
Water	4 186	1.00

Table 13-1

TABLE 13.1 Specific Heat of Selected Materials (at $T = 20°C$ unless indicated)

Material	**Specific heat c, J/(kg · °C)**	**Specific heat c, cal/(g · °C)**
Aluminum	900	0.215
Beryllium	1970	0.471
Copper	385	0.092
Ethanol	2430	0.581
Human body (average, $T = 37°C$)	3500	0.840
Ice (0°C)	2090	0.499
Iron	449	0.107
Lead	128	0.031
Mercury	140	0.033
Silver	235	0.056
Water	4186	1.000
Wood (typical)	1400	0.33
Steel (typical)	500	0.12

7. The highest recorded waterfall in the world is found at Angel Falls in Venezuela. Its longest single waterfall has a height of 807 m. If water at the top of the falls is at 15.0°C, what is the maximum temperature of the water at the bottom of the falls? Assume all the kinetic energy of the water as it reaches the bottom goes into raising the water's temperature.

11.7 As mass m of water drops from the top to the bottom of the falls, the gravitational potential energy given up (and hence, the kinetic energy gained) is $Q = mgh$. If all of this goes into raising the temperature, the rise in temperature will be

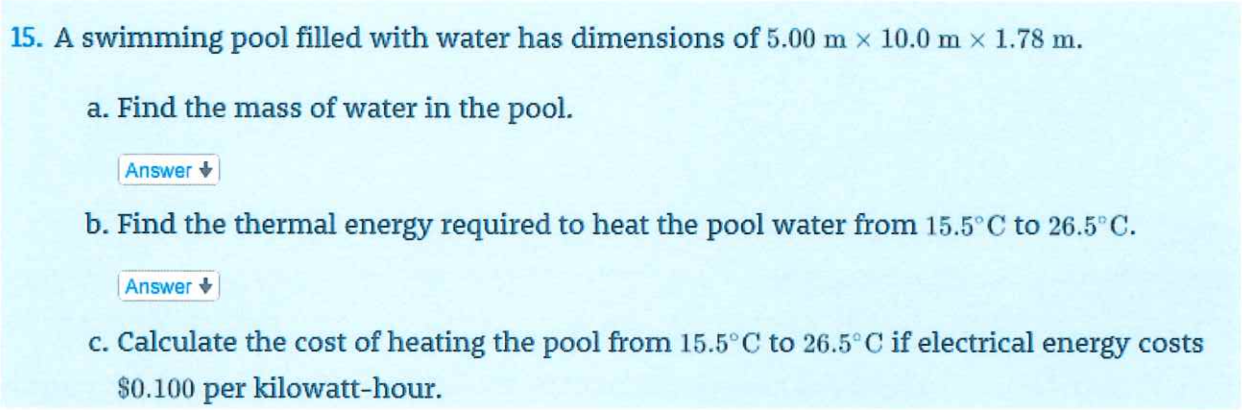
$$\Delta T = \frac{Q}{mc_{\text{water}}} = \frac{\cancel{m}gh}{\cancel{m}c_{\text{water}}} = \frac{\left(9.80\ \text{m/s}^2\right)\left(807\ \text{m}\right)}{4\,186\ \text{J/kg}\cdot{}^\circ\text{C}} = 1.89^\circ\text{C}$$

and the final temperature is $T_f = T_i + \Delta T = 15.0^\circ\text{C} + 1.89^\circ\text{C} = \boxed{16.9^\circ\text{C}}$

11. V A 5.00-g lead bullet traveling at 3.00×10^2 m/s is stopped by a large tree. If half the kinetic energy of the bullet is transformed into internal energy and remains with the bullet while the other half is transmitted to the tree, what is the increase in temperature of the bullet?

11.11 The mechanical energy transformed into internal energy of the bullet is $Q = \frac{1}{2}(KE_i) = \frac{1}{2}\left(\frac{1}{2}mv_i^2\right) = \frac{1}{4}mv_i^2$. Thus, the change in temperature of the bullet is

$$\Delta T = \frac{Q}{mc} = \frac{\frac{1}{4}\cancel{m}v_i^2}{\cancel{m}c_{\text{lead}}} = \frac{(300\text{ m/s})^2}{4(128\text{ J/kg}\cdot{}^\circ\text{C})} = \boxed{176^\circ\text{C}}$$



15. A swimming pool filled with water has dimensions of $5.00 \text{ m} \times 10.0 \text{ m} \times 1.78 \text{ m}$.

a. Find the mass of water in the pool.

b. Find the thermal energy required to heat the pool water from 15.5°C to 26.5°C.

c. Calculate the cost of heating the pool from 15.5°C to 26.5°C if electrical energy costs $\$0.100$ per kilowatt-hour.

11.15 The swimming pool has volume $V = (5.00 \text{ m}) \times (10.0 \text{ m}) \times (1.78 \text{ m}) =$

89.0 m^3.

(a) Use the definition of density to solve for the mass:

$$\rho = \frac{M}{V} \quad \rightarrow \quad M = \rho V = \left(1.00 \times 10^3 \text{ kg/m}^3\right)\left(89.0 \text{ m}^3\right) = \boxed{8.90 \times 10^4 \text{ kg}}$$

(b) From the definition of specific heat:

$$\begin{aligned} Q = mc\Delta T &= \left(8.90 \times 10^4 \text{ kg}\right)\left(4186 \text{ J/kg}\cdot{}^\circ\text{C}\right)\left(26.5^\circ\text{C} - 15.5^\circ\text{C}\right) \\ &= \boxed{4.10 \times 10^9 \text{ J}} \end{aligned}$$

(c) The cost C in dollars for this amount of energy is

$$C = 4.10 \times 10^9 \text{ J}\left(\frac{\$0.100}{\text{kW}\cdot\text{h}}\right)\left(\frac{1 \text{ kW}}{1\,000 \text{ J/s}}\right)\left(\frac{1 \text{ h}}{3\,600 \text{ s}}\right) = \boxed{\$114}$$

65. An automobile has a mass of 1 500 kg, and its aluminum brakes have an overall mass of 6.00 kg.

a. Assuming all the internal energy transformed by friction when the car stops is deposited in the brakes and neglecting energy transfer, how many times could the car be braked to rest starting from 25.0 m/s before the brakes would begin to melt? (Assume an initial temperature of 20.0° C.)

11.65 **(a)** The energy required to raise the temperature of the brakes to the melting point at 660°C is

$$Q = mc(\Delta T) = (6.00\text{ kg})(900\text{ J/kg}\cdot{}^\circ\text{C})(660^\circ\text{C} - 20.0^\circ\text{C}) = 3.46 \times 10^6\text{ J}$$

The internal energy added to the brakes on each stop is

$$Q_1 = \Delta KE = \frac{1}{2} m_{\text{car}} v_i^2 = \frac{1}{2}\left(1\,500\text{ kg}\right)\left(25.0\text{ m/s}^2\right) = 4.69 \times 10^5\text{ J}$$

The number of stops before reaching the melting point is

$$N = \frac{Q}{Q_1} = \frac{3.46 \times 10^6\text{ J}}{4.69 \times 10^5\text{ J}} = \boxed{7\text{ stops}}$$

(b) As the car stops, it transforms part of its kinetic energy into internal energy due to air resistance. As soon as the brakes rise above air temperature, they transfer energy by heat to the air. If they reach a high temperature, they transfer energy to the air very quickly.