1.5: Units, Data Tables, and Equations

This page is a draft and is under active development.

Units for Energy

The historical development of the energy concept separately for thermal and mechanical interactions, as well as the widespread use of several different systems of units, has created a multitude of energy units. But energy is energy and all forms can and should be expressed in the same basic energy unit. Fortunately, essentially everyone within the scientific and technical community has now embraced the International System (SI) system of units. The SI unit of energy is the joule, J, (rhymes with cool). All other energy units are related to the joule through an appropriate conversion factor. We will generally use SI units in this course. However, in those instances where non-SI units are commonly used, we will use both, and expect you to be able to convert back and forth. An advantage of working *exclusively* in SI is that you don't have to be concerned about unit conversions (and keeping track of them for that purpose).

The SI base units for mass, length, and time are kilogram (kg), meter (m), and second (s), respectively. Other SI units can be expressed in base units when desired. For example, a Joule is a kgm^2/s^2. The kelvin (K), the SI unit for temperature, is another independent base unit. The zero of the kelvin scale is at thermodynamic zero, the so-called "absolute zero" of temperature. (Note that "kelvin" is used without the word "degree" attached.) Although the zero of the Celsius, or centigrade, scale is not at absolute zero, the kelvin is the same size as the Celsius degree. Thus, when dealing with temperature *differences*, it is sometimes convenient to use Celsius degrees for ΔT. For example, the SI unit for specific heat, J/kg K is equal to (and will sometimes be written as) J/kg C°.

A concept closely related to energy is power: the time rate of energy change or energy transfer. The SI unit of power is a joule per second, J/s and is given the name watt, W.

Table 1.4.1: Some common energy units and conversions to SI:

- 1 kWh = 3.6 MJ
- 1 erg = 10^{-7} J
- 1 cal = 4.184 J
- 1 food Calorie (big "C" calorie) = 1 kcal = 4.184 kJ
- 1 $ft \cdot lb$ = 1.36 J
- 1 eV = 1.602×10^{-19} J
- 1 BTU = 778 $ft \cdot lb$ = 252 cal = 1.054 kJ

Table 1.4.2: SI Units related to energy:

SI Unit	Construct	Abbreviation	Expressed in base units
Joule	energy	J	$\frac{kgm^2}{s^2} = Nm$
Watt	power	W	$\frac{kgm^2}{s^3} = \frac{J}{s}$
Newton	force	N	$\frac{kgm}{s^2}$
Pascal	pressure	Pa	$\frac{kg}{ms^2} = \frac{J}{m^3} = \frac{N}{m^2}$

Thermal Data

Below is a very useful table for this course. It includes experimentally determined values of melting and boiling temperatures, heats of melting and vaporization, and specific heats for some commonly used pure substances. The subscript "p" in c_p refers to specific heat measured at constant pressure. We will discuss the importance of this in Chapter 3. We will also discuss in Chapter 3 why specific heats for solids, liquids, and gases are different.

Table 1.4.3: Table of Melting and Boiling Points, Heats of Melting and Vaporization, and Specific Heats of Some Common Substances

(at a constant pressure of one atmosphere):

Substance	Symbol (phase)	Melting Temperature T_{MP} (K)	Boiling Temperature T_{BP} (K)	Heat of Melting ΔH_{melt} (kJ/kg) (kJ/mol)	Heat of Vaporization ΔH_{vap} (kJ/kg) (kJ/mol)	Specific Heat c_p (J/Kmol) (kJ/Kkg)
Aluminum	Al(s)	933	2600	(389.18) (10.5)	(10790) (291)	(24.3) (0.900)
Bismuth	Bi(s)	544	1693	(52.2) (10.9)	(722.5) (151)	(25.7) (0.123)
Copper	Cu(s)	1356	2839	(205) (13)	(4726) (300.3)	(24.5) (0.386)
Gold	Au(s)	1336	3081	(62.8) (1.24)	(1701) (33.5)	(25.4) (0.126)
Ice (-10°C) Water Water vapor	H_2O(s) H_2O(l) H_2O(g)	273	373	(333.5) (6.01)	(2257) (40.7)	(36.9) (2.05) (75.2) (4.18) (33.6) (1.87)
Lead	Pb(s)	600	2023	(24.7) (5.12)	(858) (177.8)	(26.4) (0.128)
Sodium	Na(s) Na(l)	371	1154	(114.8) (2.64)	(4306) (99)	(28.2) (1.23) (32.7) (1.42)
Silver	Ag(s)	1235	2436	(88.2) (9.50)	(2323) (250.6)	(25.4) (0.233)
Mercury	Hg(s) Hg(l) Hg(g)	234	630	(11.3) (2.3)	(296) (59.1)	(28.3) (0.141) (28) (0.140) (20.8) (0.103)
Tungsten	W(s)	3410	5900	(184.1) (33.86)	(4812) (884.9)	(24.6) (0.134)
Nitrogen	N_2(g)	63.14	77	(25.7 (0.72)	(199.1) (5.58)	(29.0) (1.04)
Oxygen	O_2(g)	54.39	90.18	(13.9) (0.444)	(213.1) (6.82)	(29.16) (0.911)
Iron	Fe(s)	1535	3135	(247.1) (13.8)	(6260) (349.6)	(25.1) (0.449)

Useful Grouping of Energy

Below is a list of different types of energies used in this course. The types of energies are split into two categories:

- **Mechanical Energy:** Sum of kinetic and potential energies associated with the physical "objects" as a whole, not with the internal energies of the objects.
- **Internal Energy, U:** Sum of kinetic and potential energies associated with the individual molecules/atoms comprising a substance, as well as the energies associated with their atomic and nuclear energies. In Chapter 1 we mostly deal only with *changes in the energies* associated with thermal and bond energies (chemical energies).

For each energy an *indicator* characterizes an observable that directly tells us whether the corresponding energy changes. The algebraic equation for each energy tells us how that energy depends on its indicator. A summary of energies used in the course is given in the table below.

Table 1.4.4: Common Types of Energy:

Energy Type	Indicator	Algebraic Equation for Change in Energy
Internal:		
Thermal energy	temperature, T	$\Delta E_{th} = C\Delta T$

Bond energy: phase	mass of sample in a given phase, m	$\Delta E_{bond} = \pm\lvert\Delta m \Delta H\rvert$
Bond energy: chemical	number of moles of sample, n	$\Delta E_{bond} = \pm\lvert\Delta n \Delta H\rvert$
Mechanical:		
Kinetic energy	speed, |v|	$\Delta KE = \frac{1}{2} m \Delta (v^2)$
Gravitational potential energy	height, y	$\Delta PE_g = mg\Delta y$
Spring potential energy	displacement from equilibrium, |x|	$\Delta PE_{spring} = \frac{1}{2} k \Delta x^2$

Note: This list is by no means complete, and the mechanical energy systems listed here will be used in Chapter 2. They are listed here only for reference.