H A&S 220d Energy and Environment –
P.B.Rhines Spring 2009 Numbers and formulas

Some physical constants and formulas:

density, ϱ, of liquid fresh water: 10^3 kg/m^3.; of air at the Earth's surface: 1.2 kg/m^3.

g, acceleration due to gravity: 9.8 m/sec^2

kinetic energy: KE = ½ M V^2 (Joules) (M = mass, V = speed)

kinetic energy density ½ ϱ V^2 Joules/m^3 (ϱ = mass density, kg/m^3)

potential energy due to gravity force: PE= Mgh (Joules) where h is the height difference between beginning and end of the process being studied.

work: FΔX, that is, force F times distance traveled by object being forced, ΔX

rate of doing work is *'power',* equal to force times velocity

$$F\Delta X/\Delta t = FV = \Delta(KE + PE)/\Delta t$$

(KE= ½ MV^2 kinetic energy, PE= MgH where H is height of the object, g is acceleration due to gravity, Δt is time interval and V is velocity, ΔX/Δt. Units: work, energy in Joules (kg m/sec^2); power in Joules/sec = Watts

velocity of ball dropped from height h: v = $\sqrt{2gh}$

Equation of state of an ideal gas: Pv = nR_*T or P = $\square$ RT

ϱ = density (kg/m^3), T = temperature (^{0}K), P = pressure (Newtons/m^2 or kg/msec^2), v = volume (m^3), n = number of mols of gas.

R_*= 8.3145 J/mole ^{0}K is the Universal gas constant,

the other gas constant R = R*/m (m=mass of one mol of gas)

for dry air: R = 287.04 J/kg ^{0}K and m = 28.966 grams/mol

Thermal energy equation (1st law of thermodynamics):

$$\Delta E_{int} = \Delta'Q + \Delta'W$$

where E_{int} = internal thermal energy, Δ'Q=heat added, Δ'W = work done on the sample, often Δ'W = -PΔv, pressure times change in volume, v. Δ'W is often the same as force x distance above.

thermal energy of an ideal gas: C_vT (Joules) where C_v is the specific heat capacity at constant volume and T is the temperature in Kelvin degrees (measured from absolute zero, or Celcius temperature + 273.15. For air, C_v = = 719 J/kg ^{0}K

thermal energy of solids and liquids is usually given as

$$C_pT$$

where C_p is the specific heat capacity at constant pressure. For ice, C_p=2095 Joules/(kg ^{0}C). For liquid water C_p = 4180 Joules/(kg ^{0}C).

Note the Celius and Kelvin temperature scales are the same except for a constant: ^{0}K = ^{0}C+ 273.15, so the zero degrees Kelvin is 'absolute zero' where molecules cease to move.

thermal energy required to melt ice ('latent heat of melting'): 3.37 x10^5 Joules/kg

thermal energy required to evaporate (or 'boil') liquid water ('latent heat of vaporization'): L = 2.25 x 10^6 Joules/kg (latent heat at room temperature is L = 2.5 x 10^6 J/kg).

power (flow rate of energy) in a flowing river: ½ ϱV^3 A where A is the cross-section area of the river (for a uniform depth river, A =h w where h is the depth, w the width), V the speed, and ϱ the density of the water.

transport or flux of a pollutant by water or air (kg/sec): CF where C = concentration of pollutant in (kg pollutant/kg of water plus pollutant) and F = transport of water or air in kg/sec. For a river of constant depth h and width w, and constant velocity V, F = Vhw

Useful Units and Conversions

Prefixes for units in the International System

Prefix	Symbol	Power	Example	USA/Other
exa	E	10^{18}		quintillion
peta	P	10^{15}	petagram (Pg)	quadrillion/billiard
tera	T	10^{12}	terawatt (TW)	trillion/billion
giga	G	10^{9}	gigawatt (GW)	billion/milliard
mega	M	10^{6}	megawatt (MW)	million
kilo	k	10^{3}	kilogram (kg)	
hector	h	10^{2}	hectoliter (hl)	
deka	da	10^{1}	dekagram (dag)	
deci	d	10^{-1}	decimeter (dm)	
centi	c	10^{-2}	centimeter (cm)	
milli	m	10^{-3}	millimeter (mm)	
micro	□	10^{-6}	micrometer (□ m) or 'micron'	
nano	n	10^{-9}	nanosecond (ns)	
pico	p	10^{-12}	picofarad (pf)	
femto	f	10^{-15}	femtogram (fg)	
atto	a	10^{-18}		

Length:
1 meter = 100 cm = 1,000 mm = 3.281 ft = 39.37 inches (in)
1 foot = 12 inches (in) = 30.48 cm = 1/3 yard (yd)
1mile = 5,280 ft = 1.609 km
1 micron (□ m)= 10^{-6} m
1 angström (Å) = 10^{-10} m
1 nanometer = 10 Å = 10^{-9}m
Area:
1 m^2 = 10-2 are (a) = 10-4 hectare (hecto-are, ha) = 10.76391 ft^2
1 acre = 43,560 ft^2 = 4,046.86 m^2 = 0.4047 ha
1 ha = 2.4711 acre=10^4 m^2=10^{-2} km^2
Volume:
1 m^3 = 10^6 cm^3 = 10^3 liters (l) = 1.056688×10^3 quart (qt) = 264.1721 gal (U.S.)
1 liter (l) = 1.056688 quart (qt) = 0.2641721 gal (U.S.) (think of liters as 'fat quarts').
1 gallon (U.S.) = 4 qt = 3.785412 l = 0.1336806 ft^3
1 barrel (bbl) = 42 gal (U.S.) = 159 l
Time:

1 year (yr) = 3.1536×10^7seconds (s) ≈ π x 10^7 seconds
1 day (d) = 86,400 s
Mass:
1 kg = 2.2046 pounds (lbs) = 10-3 metric ton (tonne) = 1000 grams
so, 1 (metric) tonne is 1000 kg.
1 lb = 0.4535924 kg
1 metric ton = 0.9842 long ton = 1.102311 short ton
1 short ton = 2,000 lbs = 0.9071847 metric ton
1 long ton = 2,240 lbs = 1.016047 metric ton
Energy:
1 joule (J) = 0.2390057 calorie (cal) = 9.478172×10^{-4} British thermal unit (Btu)
1 cal = 4.184 J = 3.965667×10^{-3} Btu
1 food calorie = 1 Kcal = 10^3 cal = 4184 J
1 Btu = 1055.056 J = 252.1644 cal = 2.930711×10^{-4} kilowatt-hour (kWh)
1 kWh = 3.6 megajoule (MJ) = 0.8604207 Mcal = 3412.142 Btu
1 quad = 10^{15} Btu
1 exajoule = 10^{18} J (global energy consumption is about 400 exajoules per year
Power:
1 W = 1 J/s = 0.9478×10-3 Btu/s = 3.41214 Btu/hr = 1/745.7 HP
1 HP = 745.5 W = 0.706243 Btu/s = 178.1 cal/s
Pressure:
1 pascal (Pa) = 1 newton/m^2 (N/m^2); in more basic units this is 1 kg m^{-1} sec^{-2}
pressure is force (in newtons) per unit area, and using F=ma the units of pressure are as above, since acceleration is m sec^{-2}, mass is kg.
1 physical atmosphere (atm) = 101325 Pa = 760 mm of mercury (mm Hg) = 14.69. This 'atmospheric pressure' aof roughly 10^5 Pascals is equivalent to the force per unit area of a column of mercury 760 mm tall, or a column of water 10.3 meters tall.
lb-force/in^2 (psi)
1 technical atmosphere (at) = 1 kilogram-force/cm^2 (kG/cm^2)= 9.806650×104 Pa

Energy content of monochromatic visible light, E = $h\,\upsilon$ where h is Planck's constant and υ is the frequency of the light.

Wavelength	Color	KJ/mole	Kcal/mole	Photon, eV
700 nm	red	171	40.9	1.77
680 nm	red(1)	174	41.5	1.81
600 nm	yellow	199	47.7	2.07
500 nm	blue	239	57.2	2.48
400 nm	violet	299	71.5	3.10

(1) This is the wavelength of the red absorption maximum of chlorophyll
1 mole of photons = 6.023×1023 photons (Avogadro number)
Speed of light in vacuum = 299,792,458 m/s
1 electronvolt (eV) = 1.60217733×10^{-19} J
1 mole of eV = 96,499 J

Miscellaneous Useful Units and Conversions:
Universal gas constant, R = 8.314510 Pa m^3 K^{-1} mol^{-1} = 82.5 atm cm^3 K^{-1} mol^{-1}
Planck's constant, h = 6.6×1027 erg s
Specific gravity of oil (sgro) = oil density/water density at 60^0F
API gravity (0API)= 141.5/ sgro – 131.5
1 bbl oil = 136 kg for a 35 0API crude oil
Energy content of 1 bbl of crude oil = 6.1 GJ (@ 45 MJ/kg = 45 X 10^6 J/kg
1 TW = 1TJ/s= 3.1536×1019 J/yr = 5.17×109 bbl oil/yr=5 Gbbl/yr
Energy content of 1 m3 of natural gas at standard conditions (14.7 psia and 600F) = 39 MJ
Specific energy contents:
Energy content of 1 metric ton of natural gas = 49 GJ = 49 x 10^9 J

Energy content of 1 metric ton of crude oil = 45 GJ
Energy content of 1 metric ton of coal = 27 GJ (@ 27 MJ/kg)

Solar energy fluxes:
Solar energy flux (or 'power') striking the top of the Earth's atmosphere: 1368 Watts/m^2 (varying with solar activity and season, since Earth's orbit is elliptical).
Solar energy reaching 1 square meter of land in California = 5 kWh/m^2/day (that is, 5/24 kilowatts per square meter, or about 417 watts/m^2)
Solar energy reaching 1hectare in the temperate region in one year = 1.4×1010 kcal = 1.63×107 kWh = 58000 GJ/ha/year = 5.8x1013 J/hectare; 1 hectare = 10,000 m^2 = 2.471 acres
surface area of a sphere: $4\pi R^2$ where R is its radius
volume of a sphere: $4/3\ \pi R^3$