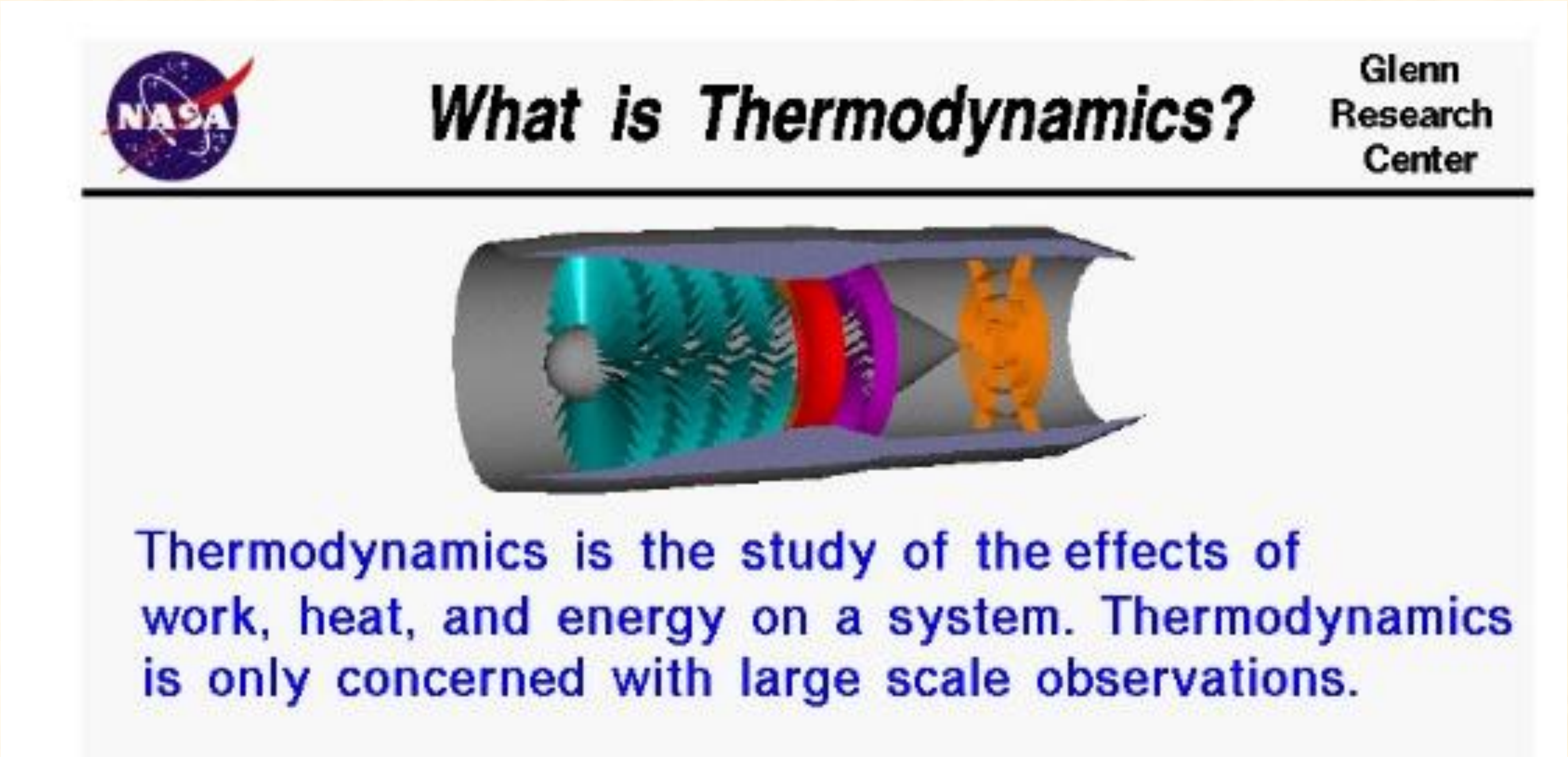
Thermodynamics



The Laws of Thermodynamics

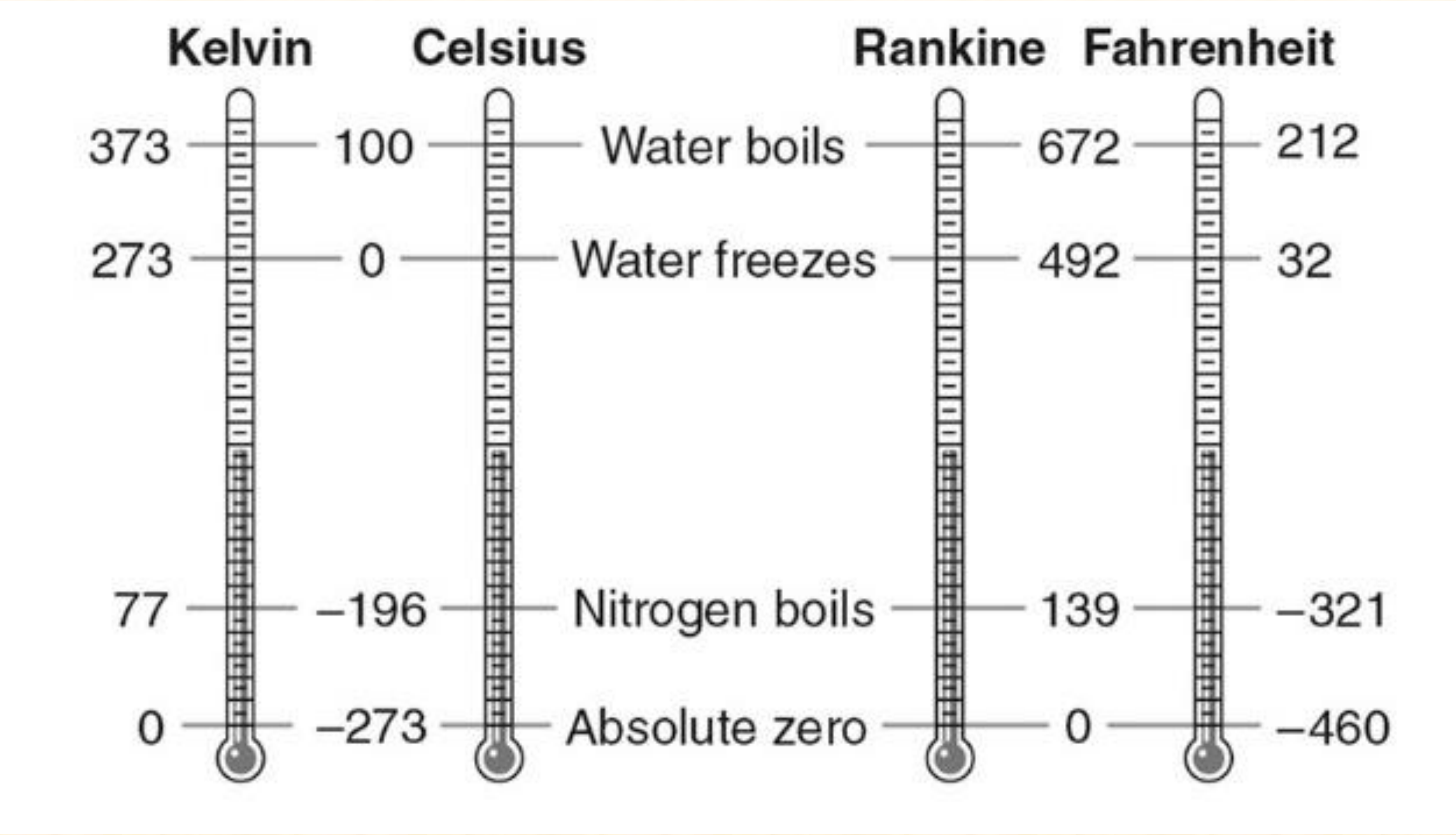
0th Law – two systems that are in thermodynamic equilibrium will not exchange heat. (You must play the game)

1st Law - the total energy of an isolated system is constant; energy can be transformed from one form to another, but can be neither created nor destroyed. (You can’t win the game, you can only break even)

2nd Law – during any irreversible (spontaneous) process the entropy of an isolated system increases. (You can only break even at absolute zero)

3rd Law - The entropy of a perfect crystal is zero when the temperature of the crystal is equal to absolute zero (0 K). (You can’t reach absolute zero)

Temperature Scales



Heat Transfer

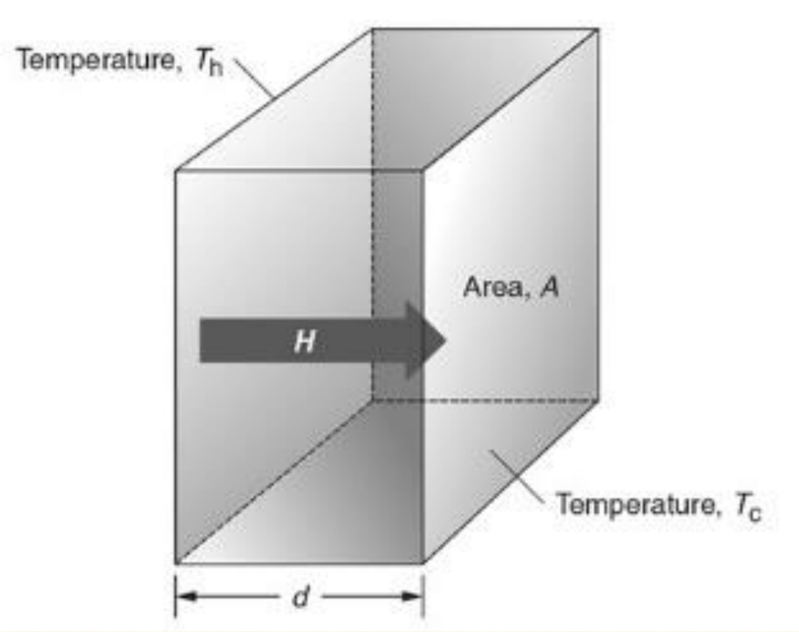
- Conduction
- Convection
- Radiation

$H = kA[(T_h - T_c)/d]$

H = heat flow (watts)
k = thermal conductivity (W/m·K)
A = area
D = thickness
T_h = temperature hot side
T_c = temperature cold side

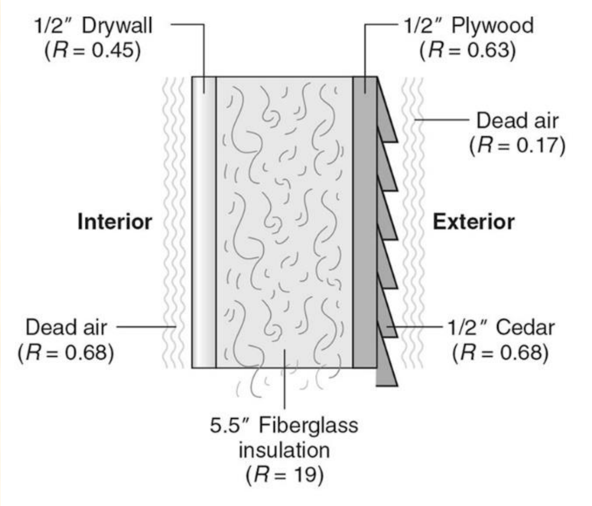
TABLE 4.1 | THERMAL CONDUCTIVITIES OF SELECTED MATERIALS

Material	Thermal conductivity (W/m·K)	Thermal conductivity (Btu·in/h·ft²·°F)
Air	0.026	0.18
Aluminum	237	1,644
Concrete (typical)	1	7
Fiberglass	0.042	0.29
Glass (typical)	0.8	5.5
Rock (granite)	3.37	23.4
Steel	46	319
Styrofoam (extruded polystyrene foam)	0.029	0.2
Urethane foam	0.022	0.15
Water	0.61	4.2
Wood (pine)	0.11	0.78



$R = d/k$

$H = A\Delta T/R$ (Btu/h)



Total R value is the sum of the individual R's

TABLE 4.2 | *R* VALUES OF SOME COMMON BUILDING MATERIALS

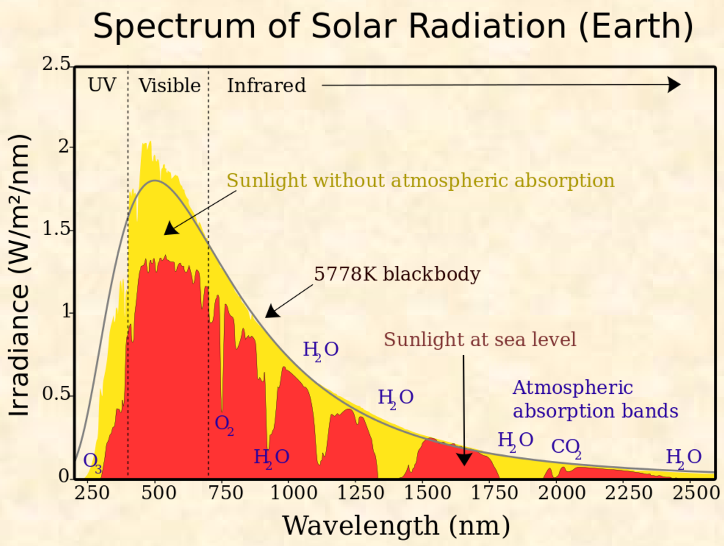
Material	*R* value ($ft^2 \cdot °F \cdot h/Btu$)*
Air layer:	
Adjacent to inside wall	0.68
Adjacent to outside wall, no wind	0.17
Cellulose, blown, 5.5-inch	20
Concrete, 8-inch	1.1
Fiberglass:	
3.5-inch	12
5.5-inch	19
Glass, 1/8-inch single pane	0.023
Gypsum board (drywall), 1/2-inch	0.45
Polystyrene foam, 1-inch	5
Urethane foam, 1-inch	6.6
Window (*R* values include adjacent air layer):	
Single-glazed wood	0.9
Standard double-glazed wood	2.0
Argon-filled double-glazed with low-E coating	2.9
Argon-filled triple-glazed with low-E coating	5.5
Best commercially available windows	11.1
Wood:	
1/2-inch cedar	0.68
3/4-inch oak	0.74
1/2-inch plywood	0.63
3/4-inch white pine	0.96

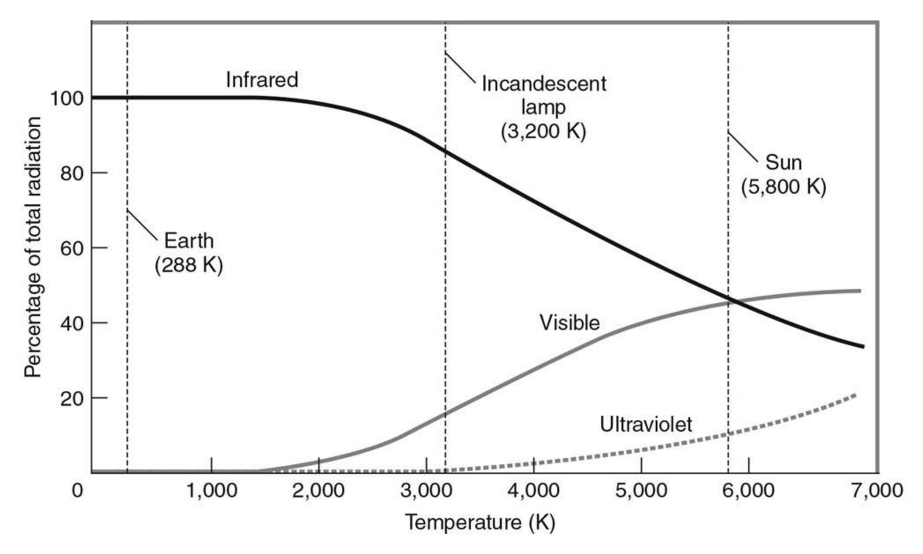
*In English units; multiply by 0.176 to convert to SI units, $m^2 \cdot K/W$.

Radiation

$P = e\sigma AT^4$

- P = power (W)
- e = emissivity (0 – 1)
- σ = Stefan-Boltzmann constant (5.67×10^{-8} $W/m^2/K^4$)
- A = area
- T = temperature (K)



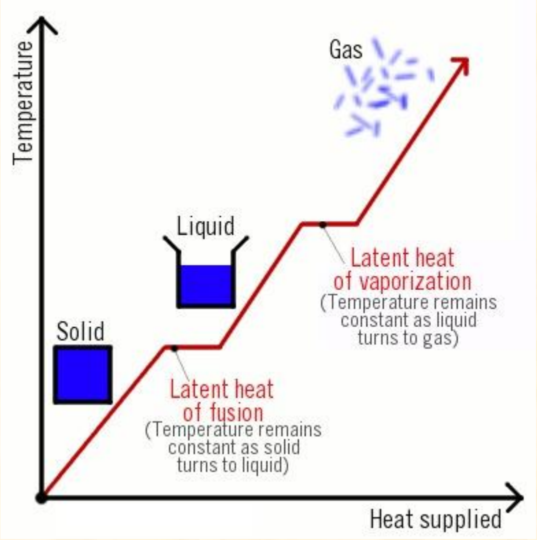


Heat Capacity

$Q = mc\Delta T$

TABLE 4.3 | SPECIFIC HEATS OF SOME COMMON MATERIALS

Material	Specific heat (J/kg·K)
Aluminum	900
Concrete	880
Glass	753
Steel	502
Stone (granite)	840
Water:	
Liquid	4,184
Ice	2,050
Wood	1,400



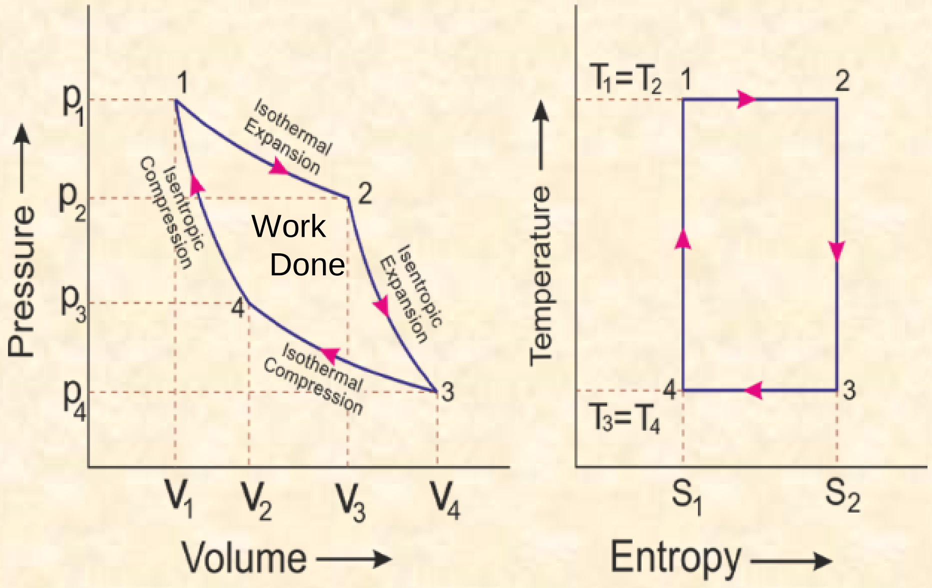
Latent Heats – involve changes of state

Table of latent heats

The following table shows the latent heats and change of phase temperatures of some common fluids and gases.

Substance	Latent Heat Fusion kJ/kg	Melting Point °C	Latent Heat Vaporization kJ/kg	Boiling Point °C
Alcohol, ethyl	108	-114	855	78.3
Ammonia	339	-75	1369	-33.34
Carbon dioxide	184	-78	574	-57
Helium			21	-268.93
Hydrogen[2]	58	-259	455	-253
Lead[8]	24.5	327.5	871	1750
Nitrogen	25.7	-210	200	-196
Oxygen	13.9	-219	213	-183
R134a		-101	215.9	-26.6
Toluene		-93	351	110.6
Turpentine			293	
Water	334	0	2260	100

Entropy, Heat Engines, and the Second Law of Themodynamics



(a) p-v diagram (b) T-S diagram

Carnot Cycle

Efficiency

e = $\frac{mechanical\ energy\ delivered}{energy\ extracted\ from\ fuel}$

$$\Delta S = \frac{\Delta H}{T}$$

Thermodynamic (Carnot) efficiency limit

e = $\frac{T_H - T_C}{T_H}$ = 1 - $\frac{T_C}{T_H}$

Heat energy that is not used to perform work is distributed to the environment as waste heat.

Cogeneration [combined heat and power (CHP)] makes use of this waste heat.

FIGURE 4.15

Energy-flow diagram for the United States in 2014, showing primary energy sources on the left and end uses and waste ("rejected energy") on the right. Numbers are in quads (10^{15} Btu).