Short Notes for Thermodynamics

Symbol/Formula	Parameter
M	Molar mass (M/μ)
m	Mass (M)
$n = \frac{m}{M}$	Number of moles (μ)
E	Energy or general extensive property
$e = \frac{E}{m}$	Specific molar energy (energy per unit mass) or general extensive property per unit mass
$\bar{e} = \frac{E}{n} = eM$	Specific energy (energy per unit mole) or general extensive property per unit mole
P	Pressure ($ML^{-1}T^{-2}$)
V	Volume (L^3); Specific volume or volume per unit mass, v (L^3M^{-1}) and the volume per unit mole $\bar{v}$ ($L^3\mu^{-1}$)
T	Temperature (Θ)
ρ	Density (ML^{-3}); $\rho = 1/v$.
x	Quality
U	Thermodynamic internal energy (ML^2T^{-2}); Internal energy per unit mass, u (L^2T^{-2}), and the internal energy per unit mole, $\bar{u}$ ($ML^2T^{-2}\mu^{-1}$)
H = U + PV	Thermodynamic enthalpy (ML^2T^{-2}); Enthalpy per unit mass, h = u + Pv (dimensions: L^2T^{-2}) and the internal energy per unit mole $\bar{h}$ ($ML^2T^{-2}\mu^{-1}$)
S	Entropy ($ML^2T^{-2}\Theta^{-1}$); Entropy per unit mass, s($L^2T^{-2}\Theta^{-1}$) and the internal energy per unit mole $\bar{s}$ ($ML^2T^{-2}\Theta^{-1}\mu^{-1}$)
W	Work (ML^2T^{-2})
Q	Heat transfer (ML^2T^{-2})
$\dot{W}_u$:	The useful work rate or mechanical power (ML^2T^{-3})
$\dot{m}$:	The mass flow rate (MT^{-1})

$\frac{\vec{V}^2}{2}$:	The kinetic energy per unit mass (L^2T^{-2})
gz:	The potential energy per unit mass (L^2T^{-2})
E_{tot}:	The total energy = $m(u + \frac{\vec{V}^2}{2} + gz)$ (ML^2T^{-2})
$\dot{Q}$:	The heat transfer rate (ML^2T^{-3})
$\frac{dE_{CV}}{dt}$:	The rate of change of energy for the control volume.(ml^2t^{-3})
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$\frac{dE_{CV}}{dt}$:	The rate of change of energy for the control volume. (ml^2t^{-3})

Unit conversion factors

For metric units

- **Basic**:
  - $1\ N = 1\ kg \cdot m/s^2$;
  - $1\ J = 1\ N \cdot m$;
  - $1\ W = 1\ J/s$;
  - $1\ Pa = 1\ N/m^2$.
- **Others**:
  - $1\ kPa \cdot m^3 = 1\ kJ$;
  - $T(K) = T(^oC) + 273.15$;
  - 1 L (liter) = $0.001\ m^3$;
  - $1\ m^2/s^2 = 1\ J/kg$.
- **Prefixes (and abbreviations)**:
  - nano(n) – 10^{-9};
  - micro(μ) – 10^{-6};
  - milli(m) – 10^{-3};
  - kilo(k) – 10^{3};
  - mega(M) – 10^{6};
  - giga(G) – 10^{9}.
  - A metric ton (European word: tonne) is 1000 kg.

For engineering units

- **Energy**:
  - 1 Btu = 5.40395 psia·ft^3 = 778.169 ft·lb_f = (1 kWh)/3412.14 = (1 hp·h)/2544.5 = 25,037 lb_m·ft^2/s^2.
- **Pressure**:
  - 1 psia = 1 lb_f/in^2 = 144 psfa = 144 lb_f/ft^2.
- **Others**:
  - T(R) = T(°F) + 459.67;
  - 1 lb_f = 32.174 lb_m· ft/s^2;
  - 1 ton of refrigeration = 200 Btu/min.

Concepts & Definitions

	Formula	Units
Pressure	$P = \frac{F}{A}$	Pa
- **Units**	$1\ Pa = 1\ N/m^2$ $1\ bar = 10^5\ Pa = 0.1\ Mpa$ $1\ atm = 101325\ Pa$	
Specific Volume	$v = \frac{V}{m}$	m^3/kg
Density	$\rho = \frac{m}{V} \rightarrow \rho = \frac{1}{v}$	kg/m^3
Static Pressure Variation	$\Delta P = \rho g h \qquad \uparrow = -\ , \downarrow = +$	Pa
Absolute Temperature	$T(K) = T(°C) + 273.15$	

Properties of a Pure Substance

	Formula	Units
Quality	$x = \frac{m_{vapor}}{m_{tot}}$ (vapour mass fraction) $1 - x = \frac{m_{liquid}}{m_{tot}}$ (Liquid mass fraction)	
Specific Volume	$v = v_f + x v_{fg}$	m^3/kg
Average Specific Volume	$v = (1-x)v_f + x v_g$ (only two phase mixture)	m^3/kg
Ideal –gas law	$P << P_c \qquad T << T_c \qquad Z = 1$	
- **Equations**	$Pv = RT \qquad PV = mRT = n\bar{R}T$	

• **Universal Gas Constant**	$\overline{R} = 8.3145$	$kJ / kmol\ K$
• **Gas Constant**	$R = \frac{\overline{R}}{M}$ $\quad M$ = molecular mass	$kJ / kg\ K$
Compressibility Factor Z	$Pv = ZRT$	
Reduced Properties	$P_r = \frac{P}{P_c} \quad , \quad T_r = \frac{T}{T_c}$	

Work & Heat

	Formula	Units
Displacement Work	$W = \int_1^2 F dx = \int_1^2 PdV$	J
Integration	$W = \int_1^2 PdV = P(V_2 - V_1)$	J
Specific Work	$w = \frac{W}{m}$ (work per unit mass)	J / kg
Power (rate of work)	$\dot{W} = F\overline{V} = P\dot{V} = T\omega$	W
• **Velocity**	$\overline{V} = r\omega$	rad / s
• **Torque**	$T = Fr$	Nm
Polytropic Process $(n \neq 1)$	$PV^n = Const = P_1V_1^n = P_2V_2^n \qquad Pv^n = C$	
• **Polytropic Exponent**	$n = \frac{\ln\left(P_2/P_1\right)}{\ln\left(V_1/V_2\right)}$	
• **n=1**	$PV = Const = P_1V_1 = P_2V_2$	
Polytropic Process Work	${}_1W_2 = \frac{1}{1-n}(P_2V_2 - P_1V_1) \qquad n \neq 1$	J
• **n=1**	${}_1W_2 = P_2V_2 \ln\left(V_2/V_1\right)$	J
Adiabatic Process	$Q = 0$	
Conduction Heat Transfer	$\dot{Q} = -kA\frac{dT}{dx}$ $\quad , k$ =conductivity	W
Convection Heat Transfer	$\dot{Q} = hA\Delta T$ $\quad , h$ =convection coefficient	W
Radiation Heat Transfer	$\dot{Q} = \varepsilon\sigma A(T_s^4 - T_{amb}^4)$	W

Terminology:

Q_1 = heat

Q_2 = heat transferred during the process between state 1 and state 2

Q = rate of heat transfer
W = work
$_1W_2$ = work done during the change from state 1 to state 2
W = rate of work = Power.   1 W=1 J/s

The First Law of Thermodynamics

	Formula	Units
Total Energy	$E = U + KE + PE \;\rightarrow\; dE = dU + d(KE) + d(PE)$	J
Energy	$dE = \delta Q - \delta W \;\rightarrow\; E_2 - E_1 = {}_1Q_2 - {}_1W_2$	J
Kinetic Energy	$KE = 0.5m\bar{V}^2$	J
Potential Energy	$PE = mgZ \rightarrow\; PE_2 - PE_1 = mg(Z_2 - Z_1)$	J
Internal Energy	$U = U_{liq} + U_{vap} \;\rightarrow\; mu = m_{liq}u_f + m_{vap}u_g$	
Specific Internal Energy of Saturated Steam (two-phase mass average)	$u = (1-x)u_f + xu_g$ $u = u_f + xu_{fg}$	kJ/kg
Total Energy	$U_2 - U_1 + \frac{m(\bar{V}_2^2 - \bar{V}_1^2)}{2} + mg(Z_2 - Z_1) = {}_1Q_2 - {}_1W_2$	J
Specific Energy	$e = u + 0.5\bar{V}^2 + gZ$	
Enthalpy	$H = U + PV$	
Specific Enthalpy	$h = u + Pv$	kJ/kg
For Ideal Gasses	$Pv = RT \;\; and \;\; u = f(T)$	
• **Enthalpy**	$h = u + Pv = u + RT$	
• **R Constant**	$u = f(t) \rightarrow h = f(T)$	
Specific Enthalpy for Saturation State (two-phase mass average)	$h = (1-x)h_f + xh_g$ $h = h_f + xh_{fg}$	kJ/kg
Specific Heat at Constant Volume	$C_v = \frac{1}{m}\left(\frac{\delta Q}{\delta T}\right)_v = \frac{1}{m}\left(\frac{\delta U}{\delta T}\right)_v = \left(\frac{\delta u}{\delta T}\right)_v$ $\rightarrow (u_e - u_i) = C_v(T_e - T_i)$	
Specific Heat at Constant Pressure	$C_p = \frac{1}{m}\left(\frac{\delta Q}{\delta T}\right)_p = \frac{1}{m}\left(\frac{\delta H}{\delta T}\right)_p = \left(\frac{\delta h}{\delta T}\right)_p$ $\rightarrow (h_e - h_i) = C_p(T_e - T_i)$	
Solids & Liquids	Incompressible, so v=constant $C = C_c = C_p$ (Tables A.3 & A.4) $u_2 - u_1 = C(T_2 - T_1)$ $h_2 - h_1 = u_2 - u_1 + v(P_2 - P_1)$	

Ideal Gas	$h = u + Pv = u + RT$ $u_2 - u_1 \cong C_v(T_2 - T_1)$ $h_2 - h_1 \cong C_p(T_2 - T_1)$
Energy Rate	$\dot{E} = \dot{Q} - \dot{W} \quad (rate = +in - out)$ $\rightarrow E_2 - E_1 = {}_1Q_2 - {}_1W_2 \quad (change = +in - out)$

First-Law Analysis for Control Volume

	Formula	Units
Volume Flow Rate	$\dot{V} = \int \bar{V} dA = A\bar{V}$ (using average velocity)	
Mass Flow Rate	$\dot{m} = \int \rho \bar{V} dA = \rho A \bar{V} = A\frac{\bar{V}}{v}$ (using average values)	kg / s
Power	$\dot{W} = \dot{m} C_p \Delta T \qquad \dot{W} = \dot{m} C_v \Delta T \qquad \dot{m} = \dot{V}/v$	W
Flow Work Rate	$\dot{W}_{flow} = P\dot{V} = \dot{m}Pv$	
Flow Direction	From higher P to lower P unless significant KE or PE	
• **Total Enthalpy**	$h_{tot} = h + \frac{1}{2}\bar{V}^2 + gZ$	
Instantaneous Process		
• **Continuity Equation**	$\dot{m}_{C.V.} = \sum \dot{m}_i - \sum \dot{m}_e$	
• **Energy Equation**	$\dot{E}_{C.V.} = \dot{Q}_{C.V.} - \dot{W}_{C.V.} + \sum \dot{m}_i h_{tot\,i} - \sum \dot{m}_e h_{tot\,e}$ → First Law $\rightarrow \dot{Q} + \sum \dot{m}_i (h_i + \frac{1}{2}\bar{V}^2 + gZ_i) = \frac{dE}{dt} + \sum \dot{m}_e \left(h_e + \frac{1}{2}\bar{V}^2 + gZ_e\right) - \dot{W}$	
Steady State Process	A steady-state has no storage effects, with all properties constant with time	
• **No Storage**	$\dot{m}_{C.V.} = 0, \quad \dot{E}_{C.V.} = 0$	
• **Continuity Equation**	$\sum \dot{m}_i = \sum \dot{m}_e$ (in = out)	
• **Energy Equation**	$\dot{Q}_{C.V.} + \sum \dot{m}_i h_{tot\,i} = \dot{W}_{C.V.} + \sum \dot{m}_e h_{tot\,e}$ (in = out) → First Law $\rightarrow \dot{Q} + \sum \dot{m}_i (h_i + \frac{1}{2}\bar{V}^2 + gZ_i) = \dot{W} + \sum \dot{m}_e \left(h_e + \frac{1}{2}\bar{V}^2 + gZ_e\right)$	
• **Specific Heat Transfer**	$q = \frac{\dot{Q}_{C.V.}}{\dot{m}}$	kJ / kg
• **Specific Work**	$w = \frac{\dot{W}_{C.V.}}{\dot{m}}$	kJ / kg
• **SS Single Flow Eq.**	$q + h_{tot\,i} = w + h_{tot\,e}$ (in = out)	
Transient Process	Change in mass (storage) such as filling or emptying of a container.	

- **Continuity Equation**	$m_2 - m_1 = \sum m_i - \sum m_e$
- **Energy Equation**	$E_2 - E_1 = Q_{C.V} - W_{C.V.} + \sum m_i h_{tot i} - \sum m_e h_{tot e}$ $E_2 - E_1 = m_2\left(u_2 + \frac{1}{2}\bar{V}_2^2 + gZ_2\right) - m_1\left(u_1 + \frac{1}{2}\bar{V}_1^2 + gZ_1\right)$
➔	$Q_{C.V} + \sum m_i h_{tot i} = \sum m_e h_{tot e} + \left[m_2\left(u_2 + \frac{1}{2}\bar{V}_2^2 + gZ_2\right) - m_1\left(u_1 + \frac{1}{2}\bar{V}_2^2 + gZ_1\right)\right]_{C.V.} - W_{C.V.}$

The Second Law of Thermodynamics

	Formula	Units
	All W, Q can also be rates $\dot{W}$, $\dot{Q}$	
Heat Engine	$W_{HE} = Q_H - Q_L$	
- **Thermal efficiency**	$\eta_{HE} = \frac{W_{HE}}{Q_H} = 1 - \frac{Q_L}{Q_H}$	
- **Carnot Cycle**	$\eta_{Thermal} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}$	
- **Real Heat Engine**	$\eta_{HE} = \frac{W_{HE}}{Q_H} \leq \eta_{Carnot\ HE} = 1 - \frac{T_L}{T_H}$	
Heat Pump	$W_{HP} = Q_H - Q_L$	
- **Coefficient of Performance**	$\beta'_{HP} = \frac{Q_H}{W_{HP}} = \frac{Q_H}{Q_H - Q_L}$	
- **Carnot Cycle**	$\beta'_{HP} = \frac{Q_H}{Q_H - Q_L} = \frac{T_H}{T_H - T_L}$	
- **Real Heat Pump**	$\beta_{HP} = \frac{Q_H}{W_{HP}} \leq \beta_{Carnot\ HP} = \frac{T_H}{T_H - T_L}$	
Refrigerator	$W_{REF} = Q_H - Q_L$	
- **Coefficient of Performance**	$\beta_{REF} = \frac{Q_L}{W_{REF}} = \frac{Q_L}{Q_H - Q_L}$	
- **Carnot Cycle**	$\beta = \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L}$	
- **Real Refrigerator**	$\beta_{REF} = \frac{Q_L}{W_{REF}} \leq \beta_{Carnot\ REF} = \frac{T_L}{T_H - T_L}$	
Absolute Temperature	$\frac{T_L}{T_H} = \frac{Q_L}{Q_H}$	

Entropy

	Formula	Units
Inequality of Clausis	$\oint \frac{\delta Q}{T} \le 0$	
Entropy	$dS \equiv \left(\frac{\delta Q}{T}\right)_{rev}$	kJ / kgK
Change of Entropy	$S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T}\right)_{rev}$	kJ / kgK
Specific Entropy	$s = (1-x)s_f + xs_g$ $s = s_f + xs_{fg}$	kJ / kgK
Entropy Change		
- **Carnot Cycle**	Isothermal Heat Transfer: $S_2 - S_1 = \frac{1}{T_H}\int_1^2 \delta Q = \frac{{}_1Q_2}{T_H}$	
	Reversible Adiabatic (Isentropic Process): $dS = \left(\frac{\delta Q}{T}\right)_{rev}$	
	Reversible Isothermal Process: $S_4 - S_3 = \int_3^4 \left(\frac{\delta Q}{T}\right)_{rev} = \frac{{}_3Q_4}{T_L}$	
	Reversible Adiabatic (Isentropic Process): Entropy decrease in process 3-4 = the entropy increase in process 1-2.	
- **Reversible Heat-Transfer Process**	$s_2 - s_1 = s_{fg} = \frac{1}{m}\int_1^2 \left(\frac{\delta Q}{T}\right)_{rev} = \frac{1}{mT}\int_1^2 \delta Q = \frac{{}_1q_2}{T} = \frac{h_{fg}}{T}$	
Gibbs Equations	$Tds = du + Pdv$ $Tds = dh - vdP$	
Entropy Generation	$dS = \frac{\delta Q}{T} + \delta S_{gen}$ $\delta W_{irr} = PdV - T\delta S_{gen}$ $S_2 - S_1 = \int_1^2 dS = \int_1^2 \frac{\delta Q}{T} + {}_1S_{2\,gen}$	
Entropy Balance Equation	$\Delta Entropy = +in - out + gen$	
Principle of the Increase of Entropy	$dS_{net} = dS_{c.m.} + dS_{surr} = \sum \delta S_{gen} \ge 0$	
Entropy Change		
- **Solids & Liquids**	$s_2 - s_1 = c \ln \frac{T_2}{T_1}$ Reversible Process: $ds_{gen} = 0$ Adiabatic Process: $dq = 0$	

• **Ideal Gas**	Constant Volume: $s_2 - s_1 = \int_1^2 Cv_0 \frac{dT}{T} + R\ln {v_2}/{v_1}$ Constant Pressure: $s_2 - s_1 = \int_1^2 Cp_0 \frac{dT}{T} - R\ln {P_2}/{P_1}$ Constant Specific Heat: $s_2 - s_1 = Cv_0 \ln {T_2}/{T_1} + R\ln {v_2}/{v_1}$ $s_2 - s_1 = Cp_0 \ln {T_2}/{T_1} - R\ln {P_2}/{P_1}$	
Standard Entropy	$s_T^0 = \int_{T_0}^{T} \frac{C_{p0}}{T} dT$	kJ / kgK
Change in Standard Entropy	$s_2 - s_1 = \left(s_{T2}^0 - s_{T1}^0\right) - R\ln {P_2}/{P_1}$	kJ / kgK
Ideal Gas Undergoing an Isentropic Process	$s_2 - s_1 = 0 = Cp_0 \ln {T_2}/{T_1} - R\ln {P_2}/{P_1}$ $\rightarrow \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{R/Cp0}$ but $\frac{R}{C_{p0}} = \frac{C_{p0} - C_{v0}}{C_{p0}} = \frac{k-1}{k}$, $k = \frac{C_{p0}}{C_{v0}}$ = ratio of specific heats $\Rightarrow \frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1}, \quad \frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^{k}$ Special case of polytropic process where k = n: $Pv^k = const$	
Reversible Polytropic Process for Ideal Gas	$PV^n = const = P_1V_1^n = P_2V_2^n$ $\rightarrow \frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n, \qquad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{n-1/n} = \left(\frac{V_1}{V_2}\right)^{n-1}$	
• **Work**	${}_1W_2 = \int_1^2 PdV = const\int_1^2 \frac{dV}{V^n} = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n}$	
• **Values for n**	Isobaric process: $n = 0, \quad P = const$ Isothermal Process: $n = 1, \quad T = const$ Isentropic Process: $n = k, \quad s = const$ Isochronic Process: $n = \infty, \quad v = const$	

Second-Law Analysis for Control Volume

	Formula	Units
2nd Law Expressed as a Change of Entropy	$\frac{dS_{c.m.}}{dt}=\sum\frac{\dot{Q}}{T}+\dot{S}_{gen}$	
Entropy Balance Equation	$rate\ of\ change=+in-out+generation$ $\rightarrow\ \frac{dS_{C.V.}}{dt}=\sum\dot{m}_i s_i-\sum\dot{m}_e s_e+\sum\frac{\dot{Q}_{C.V.}}{T}+\dot{S}_{gen}$ where $S_{C.V.}=\int\rho s dV=m_{c.v.}s=m_A s_A+m_B s_B+\ldots$ and $\dot{S}_{gen}=\int\rho\dot{s}_{gen}dV=\dot{S}_{gen.A}+\dot{S}_{gen.B}+\ldots$	
Steady State Process	$\frac{dS_{C.V.}}{dt}=0$ $\rightarrow\ \sum\dot{m}_e s_e-\sum\dot{m}_i s_i=\sum_{C.V.}\frac{\dot{Q}_{C.V.}}{T}+\dot{S}_{gen}$	
- **Continuity equation**	$\dot{m}_i=\dot{m}_e=\dot{m}\qquad\Rightarrow\dot{m}(s_e-s_i)=\sum_{C.V.}\frac{\dot{Q}_{C.V.}}{T}+\dot{S}_{gen}$	
- **Adiabatic process**	$s_e=s_i+s_{gen}\geq s_i$	
Transient Process	$\frac{d}{dt}(ms)_{C.V.}=\sum\dot{m}_i s_i-\sum\dot{m}_e s_e+\sum\frac{\dot{Q}_{C.V.}}{T}+\dot{S}_{gen}$ $\rightarrow\ (m_2 s_2-m_1 s_1)_{C.V.}=\sum m_i s_i-\sum m_e s_e+\int_0^t\frac{\dot{Q}_{C.V.}}{T}dt+{}_1\dot{S}_{2\,gen}$	
	Reversible Steady State Process	
If Process Reversible & Adiabatic	$s_e=s_i$ $h_e-h_i=\int_i^e vdP$ $w=(h_i-h_e)+\frac{\bar{V}_i^2-\bar{V}_e^2}{2}+g(Z_i-Z_e)$ $=-\int_i^e vdP+\frac{\bar{V}_i^2-\bar{V}_e^2}{2}+g(Z_i-Z_e)$	
If Process is Reversible and Isothermal	$\dot{m}(s_e-s_i)=\frac{1}{T}\sum_{C.V.}\dot{Q}_{C.V.}=\frac{Q_{C.V.}}{T}$ or $T(s_e-s_i)=\frac{\dot{Q}_{C.V.}}{\dot{m}}=q$ $\rightarrow\ T(s_e-s_i)=(h_e-h_i)-\int_i^e vdP$	

Incompressible Fluid	$v\left(P_e-P_i\right)+\frac{\bar{V}_e^2-\bar{V}_i^2}{2}+g\left(Z_e-Z_i\right)=0$ → Bernoulli Eq.
Reversible Polytrophic Process for Ideal Gas	$w=-\int_i^e vdP \quad and \quad Pv^n=const=C^n$ $w=-\int_i^e vdP=-C\int_i^e \frac{dP}{P^{1/n}}$ $=-\frac{n}{n-1}\left(P_e v_e-P_i v_i\right)=-\frac{nR}{n-1}\left(T_e-T_i\right)$
Isothermal Process (n=1)	$w=-\int_i^e vdP=-C\int_i^e \frac{dP}{P}=-P_i v_i \ln\frac{P_e}{P_i}$
Principle of the Increase of Entropy	$\frac{dS_{net}}{dt}=\frac{dS_{C.V.}}{dt}+\frac{dS_{surr}}{dt}=\sum \dot{S}_{gen}\geq 0$
Efficiency	
Turbine	$\eta=\frac{w_a}{w_s}=\frac{h_i-h_e}{h_i-h_{es}}$ Turbine work is out
Compressor (Pump)	$\eta=\frac{w_s}{w_a}=\frac{h_i-h_{es}}{h_i-h_e}$ Compressor work is in
Cooled Compressor	$\eta=\frac{w_T}{w}$
Nozzle	$\eta=\frac{1/2\,\bar{V}_e^2}{1/2\,\bar{V}_{es}^2}$ Kinetic energy is out

Note:

°F = (°C x 9/5) + 32

°C = (°F - 32) x (5/9)

°K = °C + 273

Q = mCΔT thermal energy = mass x specific heat x change in T

Q = mHf thermal energy = mass x heat of fusion

Q = mHv thermal energy = mass x heat of vaporization

ΔL = αLiΔT change in length = coefficient of expansion x initial length x change in T

ΔV = βViΔT change in volume = coefficient of expansion x initial volume x change in T

ΔU = Q – W internal energy = heat energy - work

Plausible Physical Situations		Name	State Variables	P	V	T	ΔE_{th}	Q	W_s	W
Insulated sleeve or rapid process	Add weight to or push down on piston	Adiabatic compression	$PV^{\gamma} = \text{Const}$; $TV^{\gamma-1} = \text{Const}$	Up	Down	Up	$nC_v\Delta T > 0$	0	$-nC_v\Delta T < 0$	$nC_v\Delta T > 0$
Insulated sleeve or rapid process	Remove weight from or pull up on piston	Adiabatic expansion	$PV^{\gamma} = \text{Const}$; $TV^{\gamma-1} = \text{Const}$	Down	Up	Down	$nC_v\Delta T < 0$	0	$-nC_v\Delta T > 0$	$nC_v\Delta T < 0$
Heat gas	Locked piston or rigid container	Isochoric	V fixed; $P \propto T$	Up	Fixed	Up	$nC_v\Delta T > 0$	$nC_v\Delta T > 0$	0	0
Cool gas	Locked piston or rigid container	Isochoric	V fixed; $P \propto T$	Down	Fixed	Down	$nC_v\Delta T < 0$	$nC_v\Delta T < 0$	0	0
Heat gas	Piston free to move, load unchanged	Isobaric expansion	P fixed; $V \propto T$	Fixed	Up	Up	$nC_v\Delta T > 0$	$nC_p\Delta T > 0$	$P\Delta V > 0$	$-P\Delta V < 0$
Cool gas	Piston free to move, load unchanged	Isobaric compression	P fixed; $V \propto T$	Fixed	Down	Down	$nC_v\Delta T < 0$	$nC_p\Delta T < 0$	$P\Delta V < 0$	$-P\Delta V > 0$
Immerse gas in large bath	Add weight to piston	Isothermal compression	T fixed at temperature of bath, PV = Const	Up	Down	Fixed	$nC_v\Delta T = 0$	$nRT*\ln(V_f/V_i) < 0$	$nRT*\ln(V_f/V_i) < 0$	$-nRT*\ln(V_f/V_i) > 0$
Immerse gas in large bath	Remove weight from piston	Isothermal expansion	T fixed at temperature of bath, PV = Const	Down	Up	Fixed	$nC_v\Delta T = 0$	$nRT*\ln(V_f/V_i) > 0$	$nRT*\ln(V_f/V_i) > 0$	$-nRT*\ln(V_f/V_i) < 0$
Unknown	Unknown	No Name	PV/T = Const	?	?	?	$nC_v\Delta T$	$\Delta E_{th} + W_s$	$\int PdV = \pm$ area under curve in PV diagram	$-\int PdV = \pm$ area under curve in PV diagram