



UNIVERSITI KUALA LUMPUR
Malaysian Institute of Marine Engineering Technology

FINAL EXAMINATION
OCTOBER 2025 SEMESTER SESSION

SUBJECT CODE : LGB24903

SUBJECT TITLE : THERMODYNAMICS

PROGRAMME NAME : BET IN (OFFSHORE) WITH HONOURS &
(FOR MPU: PROGRAMME LEVEL) BET IN NAVAL ARCHITECTURE AND SHIPBUILDING
WITH HONOURS

TIME / DURATION : 09.00 AM - 12.00 PM
(3 HOURS)

DATE : 30 JANUARY 2026

INSTRUCTIONS TO CANDIDATES

1. Please **CAREFULLY** read the instructions given in the question paper.
 2. This question paper has information printed on both sides of the paper.
 3. This question paper consists of TWO (2) sections; Section A and Section B.
 4. Answer ALL questions in Section A. For Section B, answer THREE (3) questions with at least ONE (1) question from question 4 or question 5.
 5. Please write your answers on the answer booklet provided.
 6. Answer all questions in English language ONLY.
 7. Formula sheet and steam table has been appended for your reference.
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THERE ARE 5 PAGES OF QUESTIONS, INCLUDING THIS COVER PAGE.

SECTION A (Total: 40 marks)

INSTRUCTION: Answer all questions. Show all the necessary calculation steps including the unity conversion ratio where appropriate and give your answer in SI unit. Please use the answer booklet provided.

Question 1

- a) A submersible instrument shows an absolute pressure of 152 kPa at a depth of 3.50 m in seawater (use density of seawater = 1025 kg/m^3).
- i) Determine the local atmospheric pressure at this location in kPa. (5 marks)
 - ii) Determine the absolute pressure at the same depth if the fluid were replaced by an oil with specific gravity 0.85. (5 marks)
 - iii) Convert the local atmospheric pressure and the oil absolute pressure into lbf/in^2 , showing all unit conversions. (4 marks)
 - iv) Convert the density of liquid with specific gravity 0.85 into g/m^3 . (2 marks)
- b) Explain the difference between absolute and gage pressure. (4 marks)

Question 2

- a) A rigid 100-liter vessel contains 3.50 kg of R-134a and the measured pressure is 550 kPa. Determine
- i) the temperature in °C, (6 marks)
 - ii) the quality, (3 marks)
 - iii) the specific enthalpy in kJ/kg, and (3 marks)
 - iv) the volume of the vapor phase in m³. (4 marks)
- b) Describe the conditions under which water vapor behaves like an ideal gas. Relate the water vapor behavior in applications such as air-conditioning and steam power plant. (4 marks)

SECTION B (Total: 60 marks)

INSTRUCTION: Answer THREE (3) questions only. Show all the necessary calculation steps including the unity conversion ratio where appropriate and give your answer in SI unit. Please use the answer booklet provided.

Question 3

a) Steam enters a nozzle steadily at 2 MPa and 350°C with an inlet cross-sectional area of 0.015 m². The mass flow rate of the steam is 6 kg/s. The steam exits the nozzle at 1.2 MPa with a velocity of 300 m/s. Heat loss from the nozzle to the surroundings is estimated to be 3 kJ/kg. Determine:

i) the velocity of the steam at the nozzle inlet in m/s unit,

(5 marks)

ii) the enthalpy at the nozzle exits in kJ/kg and the phase changes.

(11 marks)

b) Energy such as potential, kinetic and enthalpy can generally be neglected for compressors, pumps, and fans. Justify why these simplifications are acceptable.

(4 marks)

Question 4

- a) An ideal Otto cycle has a compression ratio of 10.2. At the beginning of the compression process, the air is at 105 kPa and 32°C. During the constant-volume heat addition process, the heat added to the air is 900 kJ/kg. Using variable specific heats from the air tables, determine:
- the temperature (°C), pressure (kPa), and internal energy (kJ/kg) at the end of the isentropic compression process, and
(13 marks)
 - the internal energy at the constant-volume heat addition process (kJ/kg).
(3 marks)
- b) Explain how high compression ratios can lead to engine knocks in spark-ignition engines and discuss why auto ignition is undesirable in such engines by referring to Figure 1.

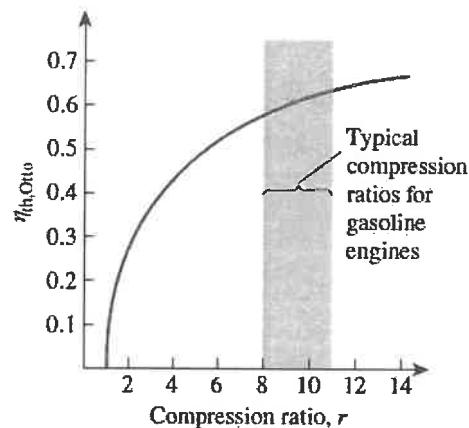


Figure 1 Thermal efficiency versus the compression ratio plot for Otto cycle

(4 marks)

Question 5

a) An ideal Rankine cycle uses steam entering the turbine at 2.5 MPa and 350°C, while the condenser pressure is maintained at 10 kPa. By fixing the properties under each state, determine:

i) the heat added in the boiler in kJ/kg, and

(12 marks)

ii) the quality of at the turbine exit.

(4 marks)

b) Identify TWO (2) common applications where two-stroke engines are used and justify why they are suitable for these uses.

(4 marks)

Question 6

(a) An ideal R-134a vapor-compression refrigeration system operates between 0.24 MPa in the evaporator and 900 kPa in the condenser. The mass flow rate of the refrigerant is 150 kg/h. Determine:

i) the compressor outlet temperature (°C),

(9 marks)

ii) the rate of heat removal from the refrigerated space (kW), and

(5 marks)

iii) the compressor power input (kW).

(2 marks)

(b) Explain the practical difficulties associated with approximating the compression process (process 2-3) and expansion process (process 4-1) of the reversed Carnot cycle in actual refrigeration systems.

(4 marks)

END OF EXAMINATION PAPER

THERMODYNAMICS FORMULA

First Law of Thermodynamics
<i>Density, $\rho = \frac{m}{V}$</i>
<i>Specific Gravity, $SG = \frac{\rho}{\rho_{H_2O}}$</i>
<i>Specific Weight, $\gamma_s = \rho g$</i>
<i>Gage Pressure, $P_{gage} = P_{abs} - P_{atm}$</i>
<i>Vacuum Pressure, $P_{vac} = P_{atm} - P_{abs}$</i>
<i>Kinetic Energy, $KE = \frac{mV^2}{2}$</i>
<i>Potential Energy, $PE = mgz$</i>
<i>Total energy, $E = U + KE + PE$</i>
<i>Heat transfer, $Q = \dot{Q}\Delta t$</i>
<i>Work, $W = Fs$</i>
<i>Force, $F = PA$</i>
<i>Spring Force, $F = kx$</i>
<i>Electrical work, $W_e = VI\Delta t$</i>
<i>Shaft work, $W_{sh} = 2\pi nT$</i>
<i>Shaft power, $\dot{W}_{sh} = 2\pi n\dot{T}$</i>
<i>Spring Work, $W_{spring} = \frac{1}{2}k(x_2^2 - x_1^2)$</i>
<i>Enthalpy, $H = U + PV$</i>
<i>Quality, $x = \frac{m_g}{m_{total}}$</i>
<i>$x = \frac{y - y_f}{y_{fg}}$ where $y = v, u$ or h</i>
<i>Mass total</i>
<i>$m_{total} = m_f + m_g$</i>
<i>Ideal gas equation</i>
<i>$PV = mRT$</i>
<i>$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$</i>

<p>General Energy Balance</p> $E_{in} - E_{out} = \Delta E_{system}$
$\Delta E_{system} = \Delta U + \Delta KE + \Delta PE$
<p>Energy Balance for a closed system</p> $\Delta Q - \Delta W = \Delta U + \Delta KE + \Delta PE$
<p>Energy Balance for a constant pressure process</p> $W_b + \Delta U = \Delta H$ $Q - W_{other} = \Delta H + \Delta KE + \Delta PE$
<p>Conservation of mass and energy equations for steady-flow process</p> $\sum \dot{m}_{in} = \sum \dot{m}_{out}$ $\dot{Q} - \dot{W} = \sum_{out} \dot{m} \left[h + \frac{v^2}{2} + gz \right] - \sum_{in} \dot{m} \left[h + \frac{v^2}{2} + gz \right]$
<p>Boundary work (P = constant), $W_b = mP_0(v_2 - v_1)$</p>
<p>Boundary work (T = constant), $W_b = P_1 V_1 \ln \left(\frac{V_2}{V_1} \right)$</p>
<p>Energy balance for a steady-flow process</p> $\dot{E}_{in} - \dot{E}_{out} = \frac{dE_{system}}{dt} = 0$ $\dot{E}_{in} = \dot{E}_{out}$
<p>Mass flow rate, $\dot{m} = \rho AV = \rho \dot{V} = \frac{\dot{V}}{v}$</p>
<p>Volume flow rate, $\dot{V} = VA = \frac{\dot{m}}{\rho}$</p>
<p>Thermal efficiency of a Heat Engine</p> $\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$
<p>Coefficient of performance</p> $COP_R = \frac{Q_L}{W_{net,in}} = \frac{q_L}{w_{net,in}} = \frac{Q_L}{Q_H - Q_L} = \frac{h_1 - h_4}{h_2 - h_1}$ $COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{q_H}{w_{net,in}} = \frac{Q_H}{Q_H - Q_L} = \frac{h_2 - h_3}{h_2 - h_1}$
<p>Carnot Heat Engine</p>
$\eta_{th,Carnot} = \eta_{th,rev} = 1 - \frac{T_L}{T_H}$

Carnot Refrigerators and Heat Pumps
$COP_{R, \text{carnot}} = \frac{1}{T_H / T_L - 1}$
$COP_{R, \text{carnot}} = \frac{1}{1 - T_L / T_H}$
Entropy
$S_{gen} = \Delta S_{total} = \Delta S_{sys} + \Delta S_{surr} \geq 0$
$\Delta S = m(s_2 - s_1)$
The Entropy Change of Ideal Gases
Constant Specific Heats (Approximate Analysis)
$s_2 - s_1 = c_{v,avg} \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$
$s_2 - s_1 = c_{p,avg} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$
Variable Specific Heats (Exact Analysis)
$s_2 - s_1 = s_2^o - s_1^o - R \ln \frac{P_2}{P_1}$
Isentropic Processes of Ideal Gases
Constant Specific Heats (Approximate Analysis)
$\left(\frac{T_2}{T_1}\right) = \left(\frac{v_1}{v_2}\right)^{k-1}$
$\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$
$\left(\frac{P_2}{P_1}\right) = \left(\frac{v_1}{v_2}\right)^k$
Variable Specific Heats (Exact Analysis)
$\left(\frac{P_2}{P_1}\right) = \frac{P_{r2}}{P_{r1}}$
$\left(\frac{v_2}{v_1}\right) = \frac{v_{r2}}{v_{r1}}$
Isentropic Efficiency of Turbine, $\eta_T = \frac{w_a}{w_s} \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$
Isentropic Efficiency of Compressors, $\eta_C = \frac{w_s}{w_a} \cong \frac{h_{2s} - h_1}{h_{2a} - h_1}$
Isentropic Efficiency of Pump, $\eta_P = \frac{w_s}{w_a} \cong \frac{v(P_2 - P_1)}{h_{2a} - h_1}$

<i>Isentropic Efficiency of Nozzle, $\eta_N = \frac{v_{2a}^2}{v_{2s}^2} \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$</i>
Gas Power Cycle
<i>Compression ratio, $r = \frac{V_{max}}{V_{min}} = \frac{V_{BDC}}{V_{TDC}} = \frac{V_1}{V_2} = \frac{v_1}{v_2}$</i>
<i>Mean Effective Pressure, $MEP = \frac{W_{net}}{V_{max} - V_{min}} = \frac{w_{net}}{v_{max} - v_{min}}$</i>
Otto Cycle
$q_{in} = u_3 - u_2 = c_v(T_3 - T_2)$
$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$
$\eta_{th,Otto} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$
$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}}$
Diesel Cycle
$q_{in} - w_{b,out} = u_3 - u_2 \rightarrow q_{in} = P_2(v_3 - v_2) + (u_3 - u_2) = h_3 - h_2 = c_p(T_3 - T_2)$
$-q_{out} = u_1 - u_4 \rightarrow q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$
$\eta_{th,Diesel} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{k(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{kT_2(T_3/T_2 - 1)}$
$\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}} \left[\frac{r_c^k - 1}{k(r_c - 1)} \right]$
$r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$
Rankine Cycle
<i>Pump ($q = 0$): $w_{pump,in} = h_2 - h_1$ where $h_1 = h_{f@P_1}$</i>
<i>or $w_{pump,in} = v(P_2 - P_1)$ where $v \cong v_1 = v_{f@P_1}$</i>
<i>Boiler ($w = 0$): $q_{in} = h_3 - h_2$</i>
<i>Turbine ($q = 0$): $w_{turb,out} = h_3 - h_4$</i>
<i>Condenser ($w = 0$): $q_{out} = h_4 - h_1$</i>
$w_{net} = q_{in} - q_{out} = w_{turb,out} - w_{pump,in}$
Isentropic Efficiencies for Pumps and Turbines
$\eta_P = \frac{w_s}{w_a} = \frac{h_{2s} - h_1}{h_{2a} - h_1}$
$\eta_T = \frac{w_a}{w_s} = \frac{h_3 - h_{4a}}{h_3 - h_{4s}}$

Ideal Reheat Rankine Cycle
$q_{in} = q_{primary} + q_{reheat} = (h_3 - h_2) + (h_5 - h_4)$
$w_{turb,out} = w_{turb,I} + w_{turb,II} = (h_3 - h_4) + (h_5 - h_6)$
Partial Pressure of Dry Air and Water vapor
$P = P_a + P_v$
Enthalpy of Dry Air and Water vapor
$h_{dry\ air} = c_p T = (1.005\text{kJ/kg}\cdot^\circ\text{C})T$
$\Delta h_{dry\ air} = c_p \Delta T = (1.005\text{kJ/kg}\cdot^\circ\text{C})\Delta T$
$h_v(T, \text{low } P) \cong h_g(T)$
$h_g(T) \cong 2500.9 + 1.82T$
Specific and Relative Humidity of Air
$\omega = \frac{m_v}{m_a} = \frac{P_v V / R_v T}{P_a V / R_a T} = \frac{P_v / R_v}{P_a / R_a} = 0.622 \frac{P_v}{P_a} = \frac{0.622 P_v}{P - P_v}$
$\phi = \frac{m_v}{m_g} = \frac{P_v V / R_v T}{P_g V / R_g T} = \frac{P_v}{P_g} \quad \text{where } P_g = P_{sat@T}$
$\phi = \frac{\omega P}{(0.622 + \omega) P_g}$
$\omega = \frac{0.622 \phi P_g}{P - \phi P_g}$
$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg2}}{h_{g1} - h_{f2}}$
$\omega_2 = \frac{0.622 P_{g2}}{P_2 - P_{g2}}$
Total Enthalpy of Atmospheric Air
$H = H_a + H_v = m_a h_a + m_v h_v$
$h = h_a + \omega h_g$
Dew Point Temperature
$T_{dp} = T_{sat@P_v}$

Conversion Factors

DIMENSION	METRIC	METRIC/ENGLISH
Acceleration	1 m/s ² = 100 cm/s ²	1 m/s ² = 3.2808 ft/s ² 1 ft/s ² = 0.3048* m/s ²
Area	1 m ² = 10 ⁴ cm ² = 10 ⁶ mm ² = 10 ⁻⁶ km ²	1 m ² = 1550 in ² = 10.764 ft ² 1 ft ² = 144 in ² = 0.09290304* m ²
Density	1 g/cm ³ = 1 kg/L = 1000 kg/m ³	1 g/cm ³ = 62.428 lbm/ft ³ = 0.036127 lbm/in ³ 1 lbm/in ³ = 1728 lbm/ft ³ 1 kg/m ³ = 0.062428 lbm/ft ³
Energy, heat, work, internal energy, enthalpy	1 kJ = 1000 J = 1000 N·m = 1 kPa·m ³ 1 kJ/kg = 1000 m ² /s ² 1 kWh = 3600 kJ 1 cal [†] = 4.184 J 1 IT cal [†] = 4.1868 J 1 Cal [†] = 4.1868 kJ	1 kJ = 0.94782 Btu 1 Btu = 1.055056 kJ = 5.40395 psia·ft ³ = 778.169 lbf·ft 1 Btu/lbm = 25.037 ft ² /s ² = 2.326* kJ/kg 1 kJ/kg = 0.430 Btu/lbm 1 kWh = 3412.14 Btu 1 therm = 10 ⁵ Btu = 1.055 × 10 ⁴ kJ (natural gas)
Force	1 N = 1 kg·m/s ² = 10 ⁵ dyne 1 kgf = 9.80665 N	1 N = 0.22481 lbf 1 lbf = 32.174 lbm·ft/s ² = 4.44822 N
Heat flux	1 W/cm ² = 10 ⁴ W/m ²	1 W/m ² = 0.3171 Btu/h·ft ²
Heat transfer coefficient	1 W/m ² ·°C = 1 W/m ² ·K	1 W/m ² ·°C = 0.17612 Btu/h·ft ² ·°F
Length	1 m = 100 cm = 1000 mm = 10 ⁶ μm 1 km = 1000 m	1 m = 39.370 in = 3.2808 ft = 1.0926 yd 1 ft = 12 in = 0.3048* m 1 mile = 5280 ft = 1.6093 km 1 in = 2.54* cm
Mass	1 kg = 1000 g 1 metric ton = 1000 kg	1 kg = 2.2046226 lbm 1 lbm = 0.45359237* kg 1 ounce = 28.3495 g 1 slug = 32.174 lbm = 14.5939 kg 1 short ton = 2000 lbm = 907.1847 kg
Power, heat transfer rate	1 W = 1 J/s 1 kW = 1000 W = 1.341 hp 1 hp [†] = 745.7 W	1 kW = 3412.14 Btu/h = 737.56 lbf·ft/s 1 hp = 550 lbf·ft/s = 0.7068 Btu/s = 42.41 Btu/min = 2544.5 Btu/h = 0.74570 kW 1 boiler hp = 33,475 Btu 1 Btu/h = 1.055056 kJ/h 1 ton of refrigeration = 200 Btu/min
Pressure	1 Pa = 1 N/m ² 1 kPa = 10 ³ Pa = 10 ⁻³ MPa 1 atm = 101.325 kPa = 1.01325 bars = 760 mm Hg at 0°C = 1.03323 kgf/cm ² 1 mm Hg = 0.1333 kPa	1 Pa = 1.4504 × 10 ⁻⁴ psia = 0.020886 lbf/ft ² 1 psi = 144 lbf/ft ² = 6.894757 kPa 1 atm = 14.696 psia = 29.92 in Hg at 30°F 1 in Hg = 3.387 kPa
Specific heat	1 kJ/kg·°C = 1 kJ/kg·K = 1 J/g·°C	1 Btu/lbm·°F = 4.1868 kJ/kg·°C 1 Btu/lbmol·R = 4.1868 kJ/kmol·K 1 kJ/kg·°C = 0.23885 Btu/lbm·°F = 0.23885 Btu/lbm·R

*Exact conversion factor between metric and English units.

†Calorie is originally defined as the amount of heat needed to raise the temperature of 1 g of water by 1°C, but it varies with temperature. The international steam table (IT) calorie (generally preferred by engineers) is exactly 4.1868 J by definition and corresponds to the specific heat of water at 15°C. The thermochemical calorie (generally preferred by physicists) is exactly 4.184 J by definition and corresponds to the specific heat of water at room temperature. The difference between the two is about 0.06 percent, which is negligible. The capitalized Calorie used by nutritionists is actually a kilocalorie (1000 IT calories).

DIMENSION	METRIC	METRIC/ENGLISH
Specific volume	$1 \text{ m}^3/\text{kg} = 1000 \text{ L}/\text{kg} = 1000 \text{ cm}^3/\text{g}$	$1 \text{ m}^3/\text{kg} = 16.02 \text{ ft}^3/\text{lbm}$ $1 \text{ ft}^3/\text{lbm} = 0.062428 \text{ m}^3/\text{kg}$
Temperature	$T(\text{K}) = T(^{\circ}\text{C}) + 273.15$ $\Delta T(\text{K}) = \Delta T(^{\circ}\text{C})$	$T(\text{R}) = T(^{\circ}\text{F}) + 459.67 = 1.8T(\text{K})$ $T(^{\circ}\text{F}) = 1.8T(^{\circ}\text{C}) + 32$ $\Delta T(^{\circ}\text{F}) = \Delta T(\text{R}) = 1.8\Delta T(\text{K})$
Thermal conductivity	$1 \text{ W}/\text{m}\cdot^{\circ}\text{C} = 1 \text{ W}/\text{m}\cdot\text{K}$	$1 \text{ W}/\text{m}\cdot^{\circ}\text{C} = 0.57782 \text{ Btu}/\text{h}\cdot\text{ft}\cdot^{\circ}\text{F}$
Velocity	$1 \text{ m}/\text{s} = 3.60 \text{ km}/\text{h}$	$1 \text{ m}/\text{s} = 3.2808 \text{ ft}/\text{s} = 2.237 \text{ mi}/\text{h}$ $1 \text{ mi}/\text{h} = 1.46667 \text{ ft}/\text{s}$ $1 \text{ mi}/\text{h} = 1.6093 \text{ km}/\text{h}$
Volume	$1 \text{ m}^3 = 1000 \text{ L} = 10^6 \text{ cm}^3 (\text{cc})$	$1 \text{ m}^3 = 6.1024 \times 10^4 \text{ in}^3 = 35.315 \text{ ft}^3$ $= 264.17 \text{ gal (U.S.)}$ $1 \text{ U.S. gallon} = 231 \text{ in}^3 = 3.7854 \text{ L}$ $1 \text{ fl ounce} = 29.5735 \text{ cm}^3 = 0.0295735 \text{ L}$ $1 \text{ U.S. gallon} = 128 \text{ fl ounces}$
Volume flow rate	$1 \text{ m}^3/\text{s} = 60,000 \text{ L}/\text{min} = 10^6 \text{ cm}^3/\text{s}$	$1 \text{ m}^3/\text{s} = 15,850 \text{ gal}/\text{min (gpm)} = 35.315 \text{ ft}^3/\text{s}$ $= 2118.9 \text{ ft}^3/\text{min (cfm)}$

⁴Mechanical horsepower. The electrical horsepower is taken to be exactly 746 W.

Some Physical Constants

Universal gas constant	$R_u = 8.31447 \text{ kJ}/\text{kmol}\cdot\text{K}$ $= 8.31447 \text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K}$ $= 0.0831447 \text{ bar}\cdot\text{m}^3/\text{kmol}\cdot\text{K}$ $= 82.05 \text{ L}\cdot\text{atm}/\text{kmol}\cdot\text{K}$ $= 1.9858 \text{ Btu}/\text{lbmol}\cdot\text{R}$ $= 1545.37 \text{ ft}\cdot\text{lb}/\text{lbmol}\cdot\text{R}$ $= 10.73 \text{ psia}\cdot\text{ft}^3/\text{lbmol}\cdot\text{R}$
Standard acceleration of gravity	$g = 9.80665 \text{ m}/\text{s}^2$ $= 32.174 \text{ ft}/\text{s}^2$
Standard atmospheric pressure	$1 \text{ atm} = 101.325 \text{ kPa}$ $= 1.01325 \text{ bar}$ $= 14.696 \text{ psia}$ $= 760 \text{ mm Hg } (0^{\circ}\text{C})$ $= 29.9213 \text{ in Hg } (32^{\circ}\text{F})$ $= 10.3323 \text{ m H}_2\text{O } (4^{\circ}\text{C})$
Stefan-Boltzmann constant	$\alpha = 5.6704 \times 10^{-8} \text{ W}/\text{m}^2\cdot\text{K}^4$ $= 0.1714 \times 10^{-8} \text{ Btu}/\text{h}\cdot\text{ft}^2\cdot\text{R}^4$
Boltzmann's constant	$k = 1.380650 \times 10^{-23} \text{ J}/\text{K}$
Speed of light in vacuum	$c_s = 2.9979 \times 10^8 \text{ m}/\text{s}$ $= 9.836 \times 10^8 \text{ ft}/\text{s}$
Speed of sound in dry air at 0°C and 1 atm	$c = 331.36 \text{ m}/\text{s}$ $= 1089 \text{ ft}/\text{s}$
Heat of fusion of water at 1 atm	$h_{jf} = 333.7 \text{ kJ}/\text{kg}$ $= 143.5 \text{ Btu}/\text{lbm}$
Enthalpy of vaporization of water at 1 atm	$h_{fg} = 2256.5 \text{ kJ}/\text{kg}$ $= 970.12 \text{ Btu}/\text{lbm}$