



UNIVERSITI KUALA LUMPUR
Malaysian Institute of Marine Engineering Technology

FINAL EXAMINATION
FEBRUARY 2025 SEMESTER SESSION

SUBJECT CODE : LMD13703 / LMD13202

SUBJECT TITLE : FUNDAMENTAL OF THERMODYNAMICS

PROGRAMME NAME : DIPLOMA OF ENGINEERING TECHNOLOGY IN
(FOR MPU: PROGRAMME LEVEL) MARINE ENGINEERING

TIME / DURATION : 09.00 AM - 11.30 AM
(2 HOURS 30 MINUTES)

DATE : 26 JUNE 2025

INSTRUCTIONS TO CANDIDATES

1. Please read **CAREFULLY** 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** question in Section A, and **TWO (2)** questions **ONLY** in Section B.
5. Please write your answers on this answer booklet provided.
6. Answer **ALL** questions in English language **ONLY**.
7. Answer should be written in blue or black ink except for sketching, graphic and illustration.
8. Steam Table of Properties and Formula has been appended for your reference.

THERE ARE 8 PAGES OF QUESTIONS, INCLUDING THIS PAGE.

SECTION A (Total: 60 marks)

INSTRUCTION: Answer ALL questions.
Please use the answer booklet provided.

Question 1

With reference to basic concept of thermodynamics to systems and processes.

(a) Define the following with related example:

- i. Adiabatic system
- ii. Closed system
- iii. Open system

(6 marks)

(b)

- i. Convert a flow rate of **2500** liters per minute into cubic meters per second (m^3/s)
- ii. A pressure gauge reads **45** psi. Convert this pressure into Pascals (N/m^2).
- iii. The density of a substance is **0.7** lbm/ft^3 . Convert this value into kilograms per cubic meter (kg/m^3).

(6 marks)

(c) A storage reservoir is filled with seawater with a density of **1030** kg/m^3 . A diver at a certain depth measures a gauge pressure of **30000** kPa.

- i. Determine the depth (h) of the diver below the water surface in meters.
(5 marks)
- ii. Calculate the absolute pressure, (P_{abs}) experienced by the diver if atmospheric pressure is 101 kPa.
(3 marks)

Question 2

With reference to forms of energy and energy transfer of a system.

(a) Define the following:

- i. Kinetic energy
- ii. Flow energy
- iii. Mechanical energy,

(6 marks)

(b) A piston-cylinder contains steam and is heated. During this heating process:

- 100 kJ of heat is added to the steam (Q_{in}),
- 10 kJ is lost as heat to the surroundings (Q_{out}),
- 25 kJ of work is done by steam as it expands (W_{out}).

Calculate the change in the internal energy of the water for this process.

(6 marks)

(c) A wind turbine is installed in a region where the average wind speed is 12 m/s (V). The air density is 1.225 kg/m³ (ρ), and the cross-sectional area swept by the blades is 80 m² (A). Determine the:

- i. total mechanical energy (e_{mech}) of the moving air per unit mass

(2 marks)

- ii. the maximum theoretical power generation potential (\dot{E}) of the wind passing through the turbine.

(6 marks)

Question 3

With reference to Laws of thermodynamics, energies, systems, pure substance properties and entropy.

(a) Define the following:

- i. Saturated liquid
- ii. Critical point
- iii. Superheated vapor

(6 marks)

(b) A closed, well-insulated vessel contains water at a pressure of 300 kPa and a specific volume of 0.5 m³/kg.

i. Based on the given properties, determine the phase of the water (compressed liquid, saturated mixture, or superheated vapor).

(3 marks)

ii. Explain briefly how you determined the phase using thermodynamic property tables.

(3 marks)

(c) Complete Table 1 below of thermodynamics properties for water. Show all the calculations involved. Use the following abbreviations where needed:

- CL – Compressed (Subcooled) liquid
- SL – Saturated liquid
- SM – Saturated Mixture
- SV – Saturated Vapor
- SHV – Superheated Vapor

Table 1: Thermodynamics properties for water

P (kPa)	T(°C)	u, kJ/kg	h, kJ/kg	Phase Description	Quality (x)
200	(a)	(b)	1500	(c)	(d)
400	10	(e)	(f)	(g)	(h)

(8 marks)

SECTION B (Total: 40 marks)

INSTRUCTION: Answer only TWO questions.

Please use the answer booklet provided.

Question 4

With reference to Laws of thermodynamics, energies, systems, pure substance properties and entropy.

- (a) Match each region or phase (Column A) with its correct description name (Column B) as shown in Figure 1 on a T-v diagram of a pure substance undergoing a constant-pressure process.

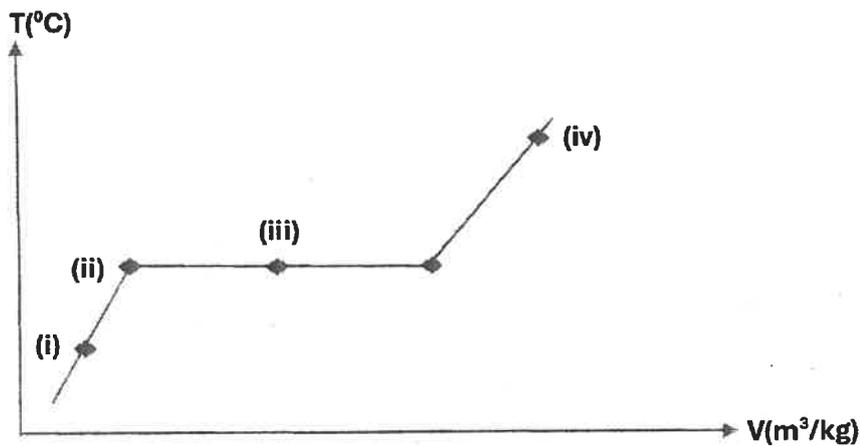


Figure 1: T-v diagram

Column A: Regions / Phases		Column B: Descriptions
i. Subcooled Liquid		A. Substance is in fully liquid and is about to vaporize
ii. Saturated liquid		B. Substance is in both liquid and vapor phases
iii. Saturated Mixture (Liquid + Vapor)		C. Substance is fully liquid, and is not about to vaporize
iv. Superheated Vapor		D. Substance is fully vapor and not about to condense

(6 marks)

- (b) A 500-liter rigid tank contains 5 kg of air at 25°C. The atmospheric pressure is 101 kPa. Match each term or value from the situation with its correct description. Write the letter of your answer (A – F) in the space provided next to each number.

Column A		Column B: Descriptions
i. Rigid tank		A. Temperature used to calculate the pressure of the air inside the tank
ii. 500 liters		B. Subtracted from the absolute pressure to calculate the gauge pressure
iii. 5kg of air		C. Volume of the air stored in the tank
iv. 25°C		D. Mass used to determine air density or specific volume
v. Atmospheric pressure (101kPa)		E. Pressure measured relative to atmospheric pressure
vi. Gauge pressure		F. Indicates that the volume of the system remains constant

(6 marks)

- (c) A rigid, closed tank contains 1.5 kg of water with a total volume of 300 liters, and the pressure is measured at 1.2 MPa.

i. Using the specific volume and pressure, identify the phase of the water (compressed liquid, saturated mixture, or superheated vapor).

(3 marks)

ii. Determine the temperature, $T(^{\circ}\text{C})$, of the water at this state using appropriate property tables.

(3 marks)

iii. Compute the internal energy per unit mass, u (kJ/kg), of the water.

(2 marks)

Question 5

With reference to Laws of thermodynamics, energies, systems, pure substance properties and entropy.

Refrigerant-134a enters a compressor at **180 kPa** as a **saturated vapor** with a volume flow rate of **0.35 m³/min** and leaves at **900 kPa**. The power input during the compression process is **2.35 kW**. Assume steady-flow, negligible changes in kinetic and potential energy.

- i. Determine the mass flow rate of the refrigerant, \dot{m} (kg/s) (4 marks)
- ii. Determine the enthalpy at the compressor outlet, h_2 (kJ/kg). (4 marks)
- iii. State the steady-flow energy equation used and identify any assumptions made. (4 marks)
- iv. Using the result of h_2 (from ii) analyze the thermodynamic state and **estimate the temperature** of R-134a at the compressor exit, T_2 ($^{\circ}\text{C}$) (8 marks)

Question 6

With reference to the second law of thermodynamics to cyclic devices.

- (a) Draw and clearly label the schematic diagram of a heat pump system. Your diagram must include:

- i. Heat absorbed, Q_L
- ii. Heat rejected, Q_H
- iii. Work input, W_{in}

(6 marks)

- (b) A heat pump supplies thermal energy to a house at a rate of 8000 kJ/h (\dot{Q}_H) for each 1 kW (\dot{W}_{in}) of electric power it draws.

- i. Determine the COP of this heat pump system,

(3 marks)

- ii. Calculate the rate of energy absorption from the outdoor air, (\dot{Q}_L) in kJ/h , for an input power of 1 kW .

(3 marks)

- (c) A heat pump operates on a Carnot heat pump cycle with a coefficient of performance (COP_{HP}) of 12.5 . It maintains the interior of a house at 24°C by consuming 2.15 kW of electric power.

- i. Calculate the temperature of the outdoor reservoir, T_L (from which heat is absorbed).

(4 marks)

- ii. Determine the heating load, (rate of heat supplied to the house) by the heat pump, Q_H (kW)

(2 marks)

- iii. Justify why a Carnot cycle is used as an ideal benchmark in this analysis

(2 marks)

END OF EXAMINATION PAPER

THERMODYNAMICS FORMULAE

First Law of Thermodynamics
$\text{Quality, } x = \frac{m_g}{m_{total}} = \frac{v - v_f}{v_{fg}}$ $v = v_f + (x)v_{fg}; \quad u = u_f + (x)u_{fg}; \quad h = h_f + (x)h_{fg}$
<p>Mass total,</p> $m_{total} = m_f + m_g$
<p>Ideal gas equation</p> $PV = mRT; \quad Pv = RT$ $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
<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, constant volume process</p> $Q - W = \Delta U + \Delta KE + \Delta PE$ <p><i>Ideal gas:</i> $Q - W = mc_v(T_2 - T_1)$</p>
<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><i>Ideal gas:</i> $Q - W = mc_p(T_2 - T_1)$</p>
<p>Conservation of mass and energy equations for steady-flow process</p> $\sum \dot{m}_{in} = \sum \dot{m}_{out}$ $\dot{Q} - \dot{W} = \sum_{out} \dot{m} [h + V^2/2 + gz] - \sum_{in} \dot{m} [h + V^2/2 + gz]$ $\dot{Q}_{in} + \dot{W}_{in} + \dot{m} \left(h_1 + \frac{V_1^2}{2} + gz_1 \right) = \dot{Q}_{out} + \dot{W}_{out} + \dot{m} \left(h_2 + \frac{V_2^2}{2} + gz_2 \right)$
<p>Boundary work ($P = \text{constant}$), $W_b = mP_0(v_2 - v_1)$</p>
<p>Boundary work ($T = \text{constant}$), $W_b = P_1V_1 \ln \left(\frac{V_2}{V_1} \right)$</p>
<p>Polytropic Process, $PV^n = C$</p> <p>Boundary work (Polytropic), $W_b = \frac{P_1V_1 - P_2V_2}{1-n}$</p>

Mass flow rate

$$\dot{m} = \rho AV = \rho \dot{V} = \frac{\dot{V}}{v}$$

Volume flow rate

$$\dot{V} = VA = \frac{\dot{m}}{\rho}$$

Thermal efficiency of a Heat Engine

$$\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

Coefficient of Performance of a Refrigerator and Heat Pump

$$COP_R = \frac{Q_L}{W_{net,in}} = \frac{q_L}{w_{net,in}} = \frac{Q_L}{Q_H - Q_L}$$

$$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{q_H}{w_{net,in}} = \frac{Q_H}{Q_H - Q_L}$$

Carnot Heat Engine

$$\eta_{th,Carnot} = \eta_{th,rev} = 1 - \frac{T_L}{T_H}$$

Carnot Refrigerators and Heat Pumps

$$COP_{R,carnot} = \frac{1}{\frac{T_H}{T_L} - 1}$$

$$COP_{HP,carnot} = \frac{1}{1 - \frac{T_L}{T_H}}$$

Isentropic Process

$$s_2 = s_1$$

$$\left(\frac{T_2}{T_1}\right)_{s=const.} = \left(\frac{v_1}{v_2}\right)^{k-1}$$

$$\left(\frac{T_2}{T_1}\right)_{s=const.} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$$

$$\left(\frac{P_2}{P_1}\right)_{s=const.} = \left(\frac{v_1}{v_2}\right)^k$$

$$\left(\frac{P_2}{P_1}\right)_{s=const.} = \frac{P_{r2}}{P_{r1}}$$

$$\left(\frac{v_2}{v_1}\right)_{s=const.} = \frac{v_{r2}}{v_{r1}}$$

Power Cycles

$$\text{Compression ratio, } r = \frac{V_{\max}}{V_{\min}} = \frac{V_{BDC}}{V_{TDC}} = \frac{V_1}{V_2} = \frac{v_1}{v_2} = \frac{v_{r1}}{v_{r2}}$$

$$MEP = \frac{W_{net}}{V_{\max} - V_{\min}} = \frac{w_{net}}{v_{\max} - v_{\min}} = \frac{w_{net}}{v \left(1 - \frac{1}{r}\right)}$$

Otto Cycle

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_{exit} - h_{inlet}$$

$$q_{in} = u_3 - u_2 = c_v(T_3 - T_2)$$

$$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$$

$$\text{Thermal efficiency, } \eta_{th,Otto} = \frac{W_{net}}{Q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

$$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}} = \text{cold-air standard}$$

Diesel Cycle

$$q_{in} = w_{b,out} + (u_3 - u_2) = P_2(v_3 - v_2) + (u_3 - u_2) = h_3 - h_2 = c_p(T_3 - T_2)$$

$$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$$

$$\text{Cutoff ratio, } r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$$

$$\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}} \left[\frac{r_c^k - 1}{k(r_c - 1)} \right] = \text{cold-air standard}$$

Joule-Brayton Cycle

$$q_{in} = w_{b,out} + (u_3 - u_2) = P_2(v_3 - v_2) + (u_3 - u_2) = h_3 - h_2 = c_p(T_3 - T_2)$$

$$q_{out} = h_4 - h_1 = c_p(T_4 - T_1)$$

$$\text{Pressure ratio, } r_p = \frac{P_2}{P_1}$$

$$\eta_{th,Brayton} = 1 - \frac{1}{r_p^{\frac{k-1}{k}}} = \text{cold-air standard}$$

Rankine Cycle

$$w_{pump,in} = h_2 - h_1 = v(P_2 - P_1)$$

$$q_{in} = h_3 - h_2$$

$$w_{turb,out} = h_3 - h_4$$

$$q_{out} = h_4 - h_1$$

$$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

$$w_{net} = q_{in} - q_{out} = w_{turb,in} - w_{pump,in}$$

Reheat Rankine Cycle

$$\text{Total heat input, } q_{in} = q_{primary} + q_{reheat} = (h_3 - h_2) + (h_5 - h_4)$$

$$q_{out} = h_6 - h_1$$

$$w_{turb,out} = w_{turb,I} + w_{turb,II} = (h_3 - h_4) + (h_5 - h_6)$$

Refrigeration Cycle

$$W_{net,out} = Q_H - Q_L$$

$$\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

$$COP_R = \frac{Q_L}{W_{net,in}} = \frac{q_L}{w_{net,in}} = \frac{Q_L}{Q_H - Q_L} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{q_H}{w_{net,in}} = \frac{Q_H}{Q_H - Q_L} = \frac{h_2 - h_3}{h_2 - h_1}$$

$$COP_{HP} = COP_R + 1$$

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 ⁵ 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/h 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	$T(\text{K}) = T(^{\circ}\text{C}) + 273.15$ $\Delta T(\text{K}) = \Delta T(^{\circ}\text{C})$	$T(\text{R}) = T(^{\circ}\text{F}) + 459.67 = 1.8T(\text{K})$ $T(^{\circ}\text{F}) = 1.8 T(^{\circ}\text{C}) + 32$ $\Delta T(^{\circ}\text{F}) = \Delta T(\text{R}) = 1.8 \Delta T(\text{K})$
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	$1 \text{ m}^3/\text{s} = 60,000 \text{ L}/\text{min} = 10^6 \text{ cm}^3/\text{s}$	$1 \text{ m}^3/\text{s} = 15,850 \text{ gal}/\text{min (gpm)} = 35.315 \text{ ft}^3/\text{s}$ $= 2118.9 \text{ ft}^3/\text{min (cfm)}$

*Mechanical 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	$\sigma = 5.6704 \times 10^{-8} \text{ W}/\text{m}^2 \cdot \text{K}^4$ $= 0.1714 \times 10^{-8} \text{ Btu}/\text{h} \cdot \text{ft}^2 \cdot \text{R}^4$
Boltzmann's constant	$k = 1.380650 \times 10^{-23} \text{ J}/\text{K}$
Speed of light in vacuum	$c_0 = 2.9979 \times 10^8 \text{ m}/\text{s}$ $= 9.836 \times 10^8 \text{ ft}/\text{s}$
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	$h_{if} = 333.7 \text{ kJ}/\text{kg}$ $= 143.5 \text{ Btu}/\text{lbm}$
Enthalpy of vaporization of water at 1 atm	$h_{fg} = 2256.5 \text{ kJ}/\text{kg}$ $= 970.12 \text{ Btu}/\text{lbm}$