University of Fort Hare
Together in Excellence

DEPARTMENT OF PHYSICS

HEAT & THERMODYNAMICS

PHY112

DEGREE EXAMINATION

MAY/JUNE 2023

Time :3 hours

Marks : 100

INTERNAL EXAMINER

Mr. M. Someketa

MODERATOR

Mr. P. Kwinana

INSTRUCTION

Answer any five (5) questions

Question 1[20 Marks]

(a) At what temperature do the Fahrenheit and Celsius scales coincide?
(b) On a hot summer day, a cubical swimming pool is filled to within 1.00 cm of the top with water at 21.0^{0}C. When the water warms to 37.0^{0}C, the pool is completely full. What is the depth of the pool.
(c) A glass flask whose volume is exactly 1000 cm^3 at 0^0 is filled with mercury at this temperature. When flask and mercury are heated to 100^0 C, 15.2 cm^3 of mercury overflow. If the coefficient of volume expansion of mercury is 0.000182 (C^0)$^{-1}$, compute the coefficient of linear expansion of the glass.
(d) Show that $\Delta\rho = -\rho\beta\Delta T$.
(e) The density of steel is 7800 kg/m^3 at 20^{0}C. Find the density at 100^{0}C.

Question 2[20 Marks]

(a) On his honeymoon James Joule travelled from England to Switzerland. He attempted to verify his idea of the interconvertibility of mechanical energy and internal energy by measuring the increase in temperature of water that fell in a waterfall. If water at the top of an alpine waterfall has a temperature of 10.0°C and then falls 50.0 m (as at Niagara Falls), what maximum temperature at the bottom of the falls could Joule expect? He did not succeed in measuring the temperature change, partly because evaporation cooled the falling water, and also because his thermometer was not sufficiently sensitive.
(b) The temperature of a silver bar rises by 10.0°C when it absorbs 1.23 kJ of energy by heat. The mass of the bar is 525 g. Determine the specific heat of silver.
(c) A 50.0-g sample of copper is at 25.0°C. If 1 200 J of energy is added to it by heat, what is the final temperature of the copper ?
(d) A 1.50-kg iron horseshoe initially at 600°C is dropped into a bucket containing 20.0 kg of water at 25.0°C. What is the final temperature? (Ignore the heat capacity of the container, and assume that a negligible amount of water boils away.)
(e) An aluminium cup of mass 200 g contains 800 g of water in thermal equilibrium at 80.0°C. The combination of cup and water is cooled uniformly so that the temperature decreases by 1.50°C per minute. At what rate is energy being removed by heat? Express your answer in watts.

Question 3[20 Marks].

(a) A combination of 0.250 kg of water at 20.0°C, 0.400 kg of aluminum at 26.0°C, and 0.100 kg of copper at 100°C is mixed in an insulated container and allowed to come to thermal equilibrium. Ignore any energy transfer to or from the container and determine the final temperature of the mixture.
(b) A water heater is operated by solar power. If the solar collector has an area of 6.00 m^2 and the intensity delivered by sunlight is 550 W/m^2, how long does it take to increase the temperature of 1.00 m^3 of water from 20.0°C to 60.0°C?
(c) A 50.0-g copper calorimeter contains 250 g of water at 20.0°C. How much steam must be condensed into the water if the final temperature of the system is to reach 50.0°C?

(d) A 3.00-g lead bullet at 30.0°C is fired at a speed of 240 m/s into a large block of ice at 0°C, in which it becomes embedded. What quantity of ice melts?

Question 4[20 Marks]

(a) How much energy is required to change a 40.0-g ice cube from ice at -10.0°C to steam at 110°C?

(b) Steam at 100°C is added to ice at 0°C. Find the amount of ice melted and the final temperature when the mass of steam is 10.0 g and the mass of ice is 50.0 g.

Question 5[20 Marks]

(a) Determine the work done on a fluid that expands from *i* to *f* as indicated in Figure P20.24.

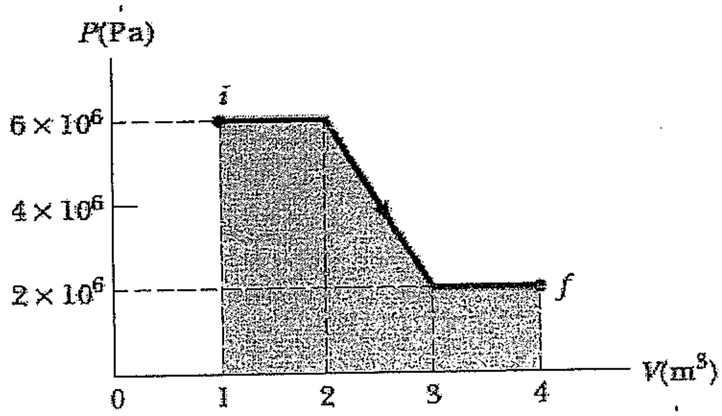

Figure P20.24

(b) A gas is taken through the cyclic process described in Figure P20.30. Find the net energy transferred to the system by heat during one complete cycle.

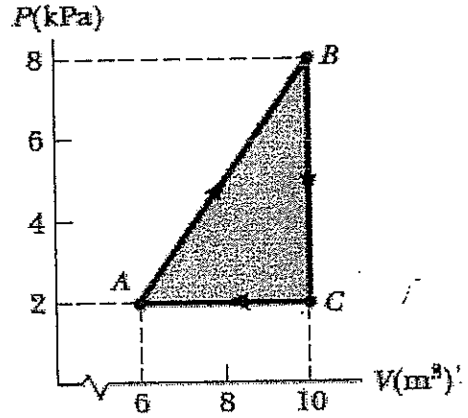

Figure P20.30 Problems 30 and 31.

(c) A sample of ideal gas is expanded to twice its original volume of 1.00 m^3 in a quasi-static process for which $P = \alpha V^2$ with α= 5.00 atm/m^6, as shown in Figure P20.23. How much work is done on the expanding gas?

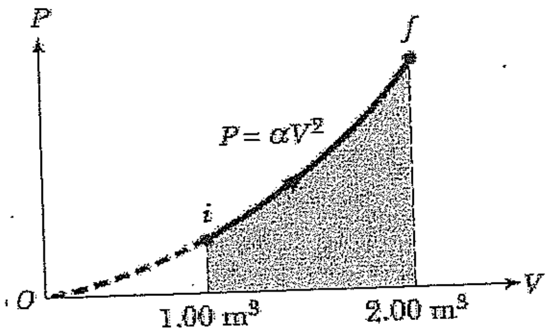

Figure P20.23

Question 6[20 Marks]

(a) A box with a total surface area of 1.20 m^2 and a wall thickness of 4.00 cm is made of an insulating material. A 10.0-W electric heater inside the box maintains the inside temperature at 15.0°C above the outside temperature. Find the thermal conductivity k of the insulating material.

(b) A bar of gold is in thermal contact with a bar of silver of the same length and area (Fig. P20.43). One end of the compound bar is maintained at 80.0°C while the opposite end is at 30.0°C. When the energy transfer reaches steady state, what is the temperature at the junction?

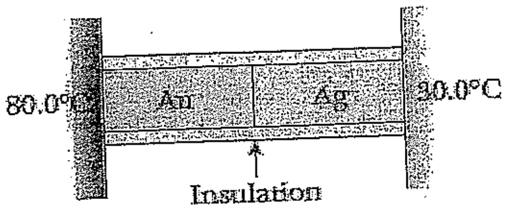

Figure P20.43

(c) The surface of the Sun has a temperature of about 5 800 K. The radius of the Sun is 6.96 x 10^8 m. Calculate the total energy radiated by the Sun each second. Assume that the emissivity of the Sun is 0.965.

(d) The tungsten filament of a certain 100-W light bulb radiates 2.00 W of light. (The other 98 W is carried away by convection and conduction.) The filament has a surface area of 0.250 mm^2 and an emissivity of 0.950. Find the filament's temperature. (The melting point of tungsten is 3 683 K.).

Question 7[20 Marks]

(a) Calculate the change in internal energy of 3.00 mol of helium gas when its temperature is increased by 2.00 K.

(b) In a constant-volume process, 209 J of energy is transferred by heat to 1.00 mol of an ideal monatomic gas initially at 300 K. Find :

(i) the increase in internal energy of the gas,

(ii) the work done on it, and

(iii) its final temperature.

(c) During the compression stroke of a certain gasoline engine,the pressure increases from 1.00 atm to 20.0 atm. If the process is adiabatic and the fuel–air mixture behaves as a diatomic ideal gas,

(i) by what factor does the volume change and

(ii) by what factor does the temperature change?

(iii) Assuming that the compression starts with 0.016 0 mol of gas at 27.0°C, find the values of *Q*, *W*, and "*E*int that characterize the process.

Question 8[20 Marks]

At point *A* in a Carnot cycle, 2.34 mol of a monatomic ideal gas has a pressure of 1 400 kPa, a volume of 10.0 L, and a temperature of 720 K. It expands isothermally to point *B*, and then expands adiabatically to point *C* where its volume is 24.0 L. An isothermal compression brings it to point *D*, where its volume is 15.0 L. An adiabatic process returns the gas to point *A*.

(a) Determine all the unknown pressures, volumes and temperatures as you fill in the following table:

	P	*V*	*T*
A	1 400 kPa	10.0 L	720 K
B			
C		24.0 L	
D		15.0 L	

(b) Find the energy added by heat, the work done by the engine, and the change in internal energy for each of the steps *A to B*, *B* to *C*, *C* to *D*, and *D to A*.

(c) Calculate the efficiency *Wnet*/*Q h* . Show that it is equal to $1 - T_c/T_h$, the Carnot efficiency.

End

Specific Heats of Some Substances at 25°C and Atmospheric Pressure

Substance	Specific heat c	
	J/kg · °C	cal/g · °C
Elemental solids		
Aluminum	900	0.215
Beryllium	1 830	0.436
Cadmium	230	0.055
Copper	387	0.092 4
Germanium	322	0.077
Gold	129	0.030 8
Iron	448	0.107
Lead	128	0.030 5
Silicon	703	0.168
Silver	234	0.056
Other solids		
Brass	380	0.092
Glass	837	0.200
Ice (−5°C)	2 090	0.50
Marble	860	0.21
Wood	1 700	0.41
Liquids		
Alcohol (ethyl)	2 400	0.58
Mercury	140	0.033
Water (15°C)	4 186	1.00
Gas		
Steam (100°C)	2 010	0.48

Molar Specific Heats of Various Gases

Gas	Molar Specific Heat (J/mol · K)[a] C_P	C_V	$C_P - C_V$	$\gamma = C_P/C_V$
Monatomic Gases				
He	20.8	12.5	8.33	1.67
Ar	20.8	12.5	8.33	1.67
Ne	20.8	12.7	8.12	1.64
Kr	20.8	12.3	8.49	1.69
Diatomic Gases				
H_2	28.8	20.4	8.33	1.41
N_2	29.1	20.8	8.33	1.40
O_2	29.4	21.1	8.33	1.40
CO	29.3	21.0	8.33	1.40
Cl_2	34.7	25.7	8.96	1.35
Polyatomic Gases				
CO_2	37.0	28.5	8.50	1.30
SO_2	40.4	31.4	9.00	1.29
H_2O	35.4	27.0	8.37	1.30
CH_4	35.5	27.1	8.41	1.31

$$\sigma = 5.6696 \times 10^{-8} W/m^2.K^4$$

Thermal Conductivities	
Substance	Thermal Conductivity (W/m · °C)
Metals (at 25°C)	
Aluminum	238
Copper	397
Gold	314
Iron	79.5
Lead	34.7
Silver	427
Nonmetals (approximate values)	
Asbestos	0.08
Concrete	0.8
Diamond	2 300
Glass	0.8
Ice	2
Rubber	0.2
Water	0.6
Wood	0.08
Gases (at 20°C)	
Air	0.023 4
Helium	0.138
Hydrogen	0.172
Nitrogen	0.023 4
Oxygen	0.023 8

Average Expansion Coefficients for Some Materials Near Room Temperature

Material	Average Linear Expansion Coefficient $(\alpha)(^\circ C)^{-1}$	Material	Average Volume Expansion Coefficient $(\beta)(^\circ C)^{-1}$
Aluminum	24×10^{-6}	Alcohol, ethyl	1.12×10^{-4}
Brass and bronze	19×10^{-6}	Benzene	1.24×10^{-4}
Copper	17×10^{-6}	Acetone	1.5×10^{-4}
Glass (ordinary)	9×10^{-6}	Glycerin	4.85×10^{-4}
Glass (Pyrex)	3.2×10^{-6}	Mercury	1.82×10^{-4}
Lead	29×10^{-6}	Turpentine	9.0×10^{-4}
Steel	11×10^{-6}	Gasoline	9.6×10^{-4}
Invar (Ni-Fe alloy)	0.9×10^{-6}	Air* at 0°C	3.67×10^{-3}
Concrete	12×10^{-6}	Helium*	3.665×10^{-3}

Latent Heats of Fusion and Vaporization

Substance	Melting Point (°C)	Latent Heat of Fusion (J/kg)	Boiling Point (°C)	Latent Heat of Vaporization (J/kg)
Helium	−269.65	5.23×10^3	−268.93	2.09×10^4
Nitrogen	−209.97	2.55×10^4	−195.81	2.01×10^5
Oxygen	−218.79	1.38×10^4	−182.97	2.13×10^5
Ethyl alcohol	−114	1.04×10^5	78	8.54×10^5
Water	0.00	3.33×10^5	100.00	2.26×10^6
Sulfur	119	3.81×10^4	444.60	3.26×10^5
Lead	327.3	2.45×10^4	1 750	8.70×10^5
Aluminum	660	3.97×10^5	2 450	1.14×10^7
Silver	960.80	8.82×10^4	2 193	2.33×10^6
Gold	1 063.00	6.44×10^4	2 660	1.58×10^6
Copper	1 083	1.34×10^5	1 187	5.06×10^6