UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:-

B.Eng. *M.Eng.*

Chemical Eng E878: Physics for Chemical Engineers

COURSE CODE	:	**CENGE878**
UNIT VALUE	:	**0.50**
DATE	:	**08-MAY-06**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

06-C0233-3-40

TURN OVER

Answer THREE questions from **Section A**, *TWO questions from* **Section B** *and TWO questions from* **Section C**.

The marks available for each question or part of each question are shown in square brackets in the right-hand margin thus... [ ]

A total of 30 marks are available from Section A, 50 from Section B and 20 from Section C.

Data

Constants:

Avogadro's constant $N_A = 6.022 \times 10^{26}$ kmol^{-1}
Boltzmann's constant, $k = 1.381 \times 10^{-23}$ J K^{-1}
Electrostatic constant, $1/4\pi\varepsilon_0 = 8.988 \times 10^9$ N m^2 C^{-2}
Gas constant, $R = 8314$ J kmol^{-1} K^{-1}
Gravitational acceleration, $g = 9.81$ m s^{-2}
Gravitational constant, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
Planck's constant, $h = 6.63 \times 10^{-34}$ J s
Stefan's constant, $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

Properties of materials:

		material			
property	*units*	Water	Air	Carbon Steel	Stainless Steel
density	kg m^{-3}	1000	1.2	7830	7750
viscosity	Pa s	1×10^{-3}	1.7×10^{-5}	-	-
specific heat capacity	J kg^{-1} K^{-1}	4180	1000	460	460
Young's modulus	N m^{-2}	-	-	20×10^{10}	19×10^{10}
shear modulus	N m^{-2}	-	-	7.8×10^{10}	6.9×10^{10}
bulk modulus	N m^{-2}	2.2×10^9	-	17×10^{10}	17×10^{10}
yield stress	N m^{-2}	-	-	3×10^8	2.8×10^8
coefficient of thermal expansion	°C^{-1}	-	$1/T$	11×10^{-6}	16×10^{-6}

Conversion factors:

1 eV = 1.602×10^{-19} J
1 mile = 1760 yard
1 yard = 36 inch
1 inch = 25.4 mm
1 ton = 2240 lb
1 lb = 0.4536 kg
1 bar = 10^5 Pa
1 atm = 1.013 bar

TURN OVER

Section A

Answer THREE multiple choice questions from this section.

A total of 30 marks are available for this section.

Select the correct option or options as required from the answers given. Justify your selection with appropriate calculations and/or explanations. Quoting a letter answer is not sufficient.

A.1 As a result of a pressure difference Δp, a liquid of density ρ and viscosity μ flows through a horizontal pipe of length l and radius r. On dimensional grounds which of the following expressions, if any, may represent the mass flow rate W of the liquid through the pipe? [10]

A: $W = \dfrac{\pi \, \Delta p^2 \, r \, \rho}{8 \, \mu \, l}$ *B*: $W = \dfrac{\pi \, \Delta p \, r^2 \, \rho}{8 \, \mu \, l}$

C: $W = \dfrac{\pi \, \Delta p \, r^4 \, \rho}{8 \, \mu \, l}$ *D*: $W = \dfrac{\pi \, \Delta p \, r^3 \, \rho}{8 \, \mu^2 \, l^2}$

A.2 An isolated object **O**, mass 5 kg, moves freely in the x-direction at a velocity, $v_{Ox} = 5 \text{ m s}^{-1}$. Suddenly, the object explodes into two parts, **P** and **Q**, of equal mass. After the explosion, **P** moves in the y-direction $v_{Py} = 4 \text{ m s}^{-1}$, velocity of **P** in the x-direction, v_{Px}, is zero. The y-direction is normal to the x-direction.

Which of the following answers, if any, represents the velocity in m s^{-1} of the object **Q** and its components? [10]

A: $v_{Qx} = 5$ *B*: $v_{Qx} = 10$

C: $v_{Qy} = 0$ *D*: $v_{Qy} = -4$ *E*: $v_{Qy} = 4$

E: $v_Q = 5$ *F*: $v_Q = 10$ *G*: $v_Q = 10.8$ *H*: $v_Q = 14$

A.3 A fire has broken out in an oil storage area. Fire crews have fire hoses from which water issues at 25 m s^{-1}. Neglecting wind resistance, what is the maximum distance that the fire crews can keep away from the fire whilst still playing water directly onto a fire at ground-level? Select the option closest to your answer. [10]

A: 30 m *B*: 45 m *C*: 60 m *D*: 75 m *E*: 90 m

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A.4 A catalyst consists of a monolayer of rhodium on a honeycomb substrate with a surface area of 170 m^2. Rhodium has an atomic weight of 102.91 and density of 12.4×10^3 kg m^{-3}. Estimate the mass of the monolayer of rhodium on the catalyst. Select the option closest to your answer. [10]

A: 0.51 kg	***B***: 0.11 kg	***C***: 21.4 g	***D***: 0.5 g
E: 0.64 g	***F***: 0.11 g	***G***: 3.2 mg	***H***: 0.5 mg

A.5 Which, if any, of the following statements are correct and which are incorrect? [10]

A: If two bodies are in thermal contact with each other, and in thermal equilibrium, then they both contain the same amount of heat.

B: If two bodies are in thermal contact with each other, and in thermal equilibrium, then they both must be at the same temperature.

C: If two bodies are separately in thermal equilibrium with a third body, then they must be in thermal equilibrium with each other irrespective of their masses, volumes, and material compositions.

D: If two bodies are separately in thermal equilibrium with a third body, then they may be in thermal equilibrium with each other but only if they are of equal mass.

E: If two bodies are in thermal contact with each other then they must also be in physical contact with each other.

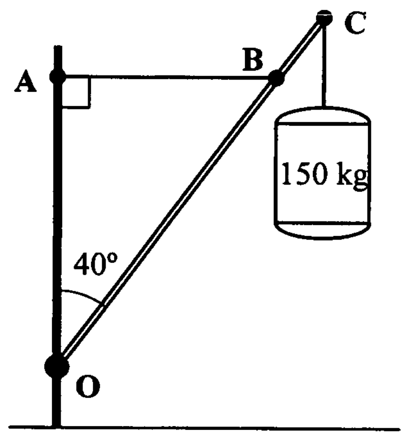
TURN OVER

Section B

Answer TWO questions from this section.
A total of 50 marks are available for this section.

B.1 During the construction of a chemical plant a piece of process equipment is lifted into position by a crane, illustrated in **Figure B.1** below. The crane arm **OC**, pivoted at **O** has a length of 20 m and has a mass of 300 kg which may be assumed to act though its centre of mass, half way between **O** and **C**. The crane arm is maintained in equilibrium by a horizontal inextensible cable of negligible mass attached to the arm at **B**, which is 18 m from **O**. The process equipment has a mass of 150 kg and hangs from **C** the end of the arm.

Figure B.1: Crane arm with process equipment



Determine:

i) The horizontal force exerted by the crane arm on the cable at **B**. [7]

ii) The force, magnitude and direction, exerted by the crane arm on the pivot **O**. [12]

ii) The torque about the pivot **O** exerted by the cable attached to the crane arm at **B**. [6]

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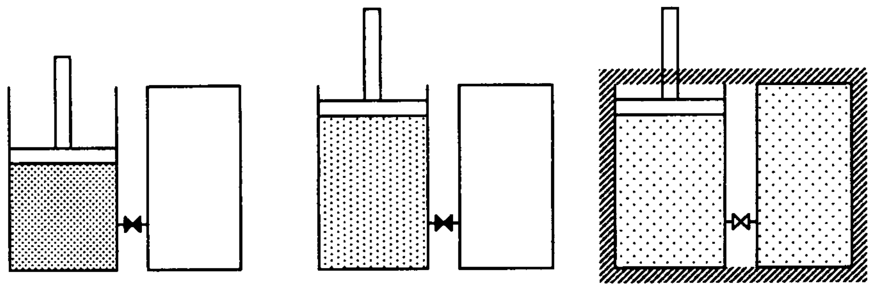
B.2 2 kg of an ideal mono-atomic gas of molecular weight 4 kg $kmol^{-1}$ are enclosed in a vertical cylinder topped by frictionless piston. The cylinder is placed next to a vessel kept under vacuum and of volume V_s = 15 m^3; the two are connected by a valve which initially is closed, see **Figure B.2**, State *A*. The gas is initially in equilibrium conditions at a pressure P_A= 5 atm and a temperature T_A = 180 °C (State *A*).

Figure B.2: Cylinder and vessel



State *A* State *B* State *C*

The gas is expended isothermally and reversibly until it reaches a pressure P_B = 2 atm (State *B*).

i) Determine the heat which has been transferred from the environment to the system throughout this process. [10]

Once the gas has reached State *B*, both cylinder and vessel are perfectly insulated from the environment (so that no heat transfer is possible), the piston is locked at its current position and the valve is opened suddenly. The gas spontaneously expands and eventually reaches a new equilibrium state (State *C*) when the temperature and pressure of the gas in the two vessels are equal.

ii) Calculate the variation of the internal energy of the gas as it is brought from State *A* to State *C* as described above. [5]

iii) Calculate the entropy generated within the gas as it is brought from State *A* to State *C* as described above. [10]

B.3 The walls of a long, horizontal, carbon steel vessel are lined on the inside with a thin layer of stainless steel to prevent corrosion from the vessel contents. The stainless steel lining is rigidly attached to the carbon steel wall and the vessel has been stress relieved so that there are no stresses in the vessel walls at ambient conditions.

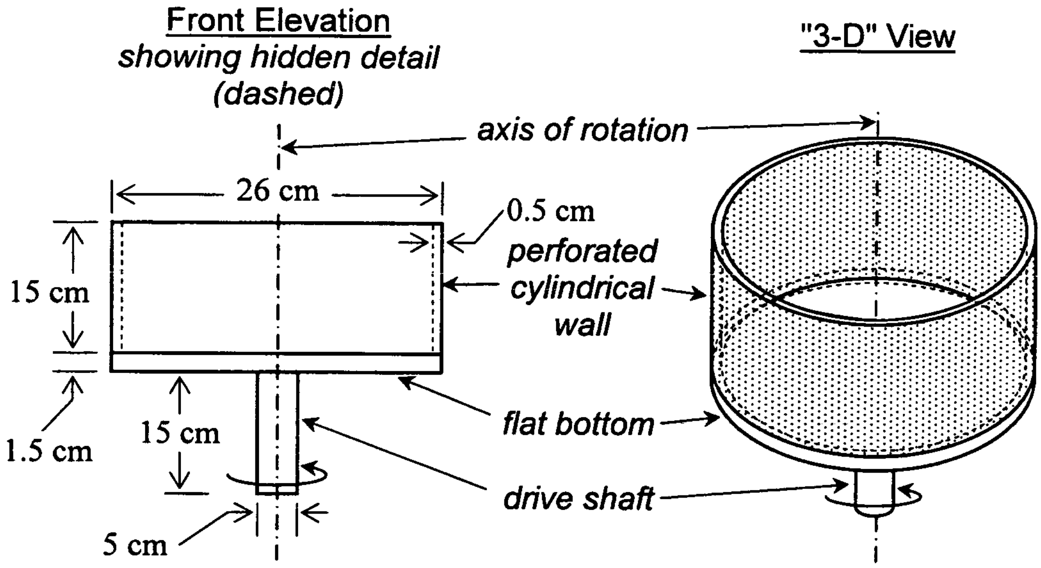
i) Calculate the fractional increase in length of the vessel as it is heated to a temperature of 140 K above ambient. [9]

ii) Calculate the horizontal stress built up in the stainless steel lining during the heating to 140 K above ambient. State whether these stresses are tensile or compressive. [16]

TURN OVER

B.4 A vertical centrifuge, illustrated in **Figure B.4** below, consists of a perforated cylindrical bowl, a solid, flat bottom, and a solid drive shaft, all constructed of stainless steel. The drive shaft is 15 cm long and 5 cm in diameter. The flat bottom is 26 cm in diameter and 1.5 cm thick. The cylindrical wall is 20 cm high, has a 26 cm outside diameter, is 0.5 cm thick and is perforated such that 50% of the metal in the wall is removed.

Figure B.4: Centrifuge - shown with wall thicknesses exaggerated

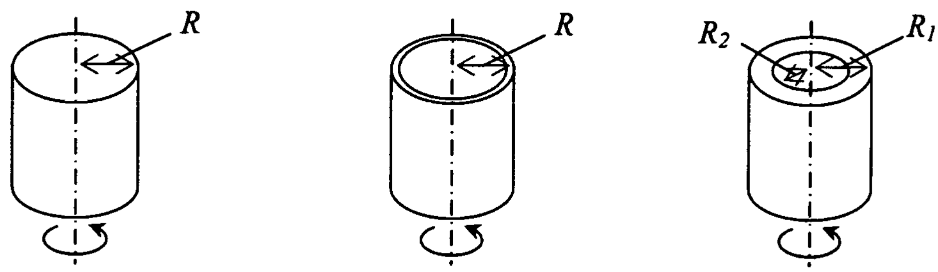


i) Using data from **Table B.4** below, estimate the *Moment of Inertia* of the centrifuge, including the drive shaft. [15]

ii) If a torque of 10 N m is applied to the drive shaft, what is the angular acceleration of the bowl? [5]

iii) At the angular acceleration calculated in ii) above, what is the time taken for the bowl top go from rest to 7000 rpm? If you do not have an answer from ii), use a value of 50 rad s^{-2} (this is not the correct answer to ii)). [5]

Table B.4: Moments of Inertia of homogeneous bodies about the indicated axes (*M* is the mass of the body)



Solid Cylinder or Disk	Thin Cylindrical Shell	Hollow Cylinder or Hoop
$I = \frac{1}{2}MR^2$	$I = MR^2$	$I = \frac{1}{2}M(R_1^2 + R_2^2)$

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Section C

*Write short notes on **TWO** of the following.*
A total of 20 marks are available for this section.

C.1 Heat transfer by radiation. [10]

C.2 Compare and contrast gravitational and electrostatic fields. [10]

C.3 The gas thermometer and its operation. [10]

C.4 Sketch and describe the salient features of the loading curve of stress against strain for a typical material. [10]

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