SUMMER-19 EXAMINATION

Model Answer

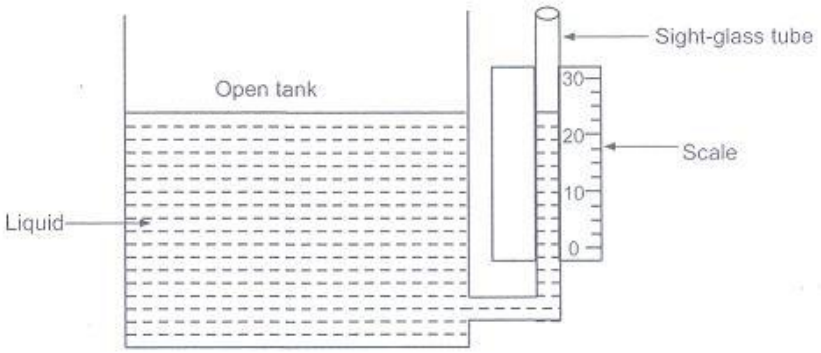
Subject title: Chemical Process Instrumentation & Control Subject code 17561

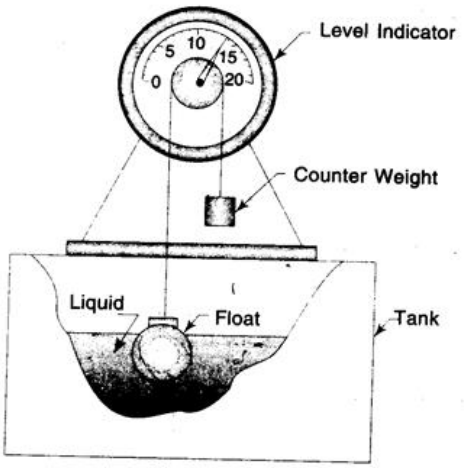
Important Instructions to examiners:

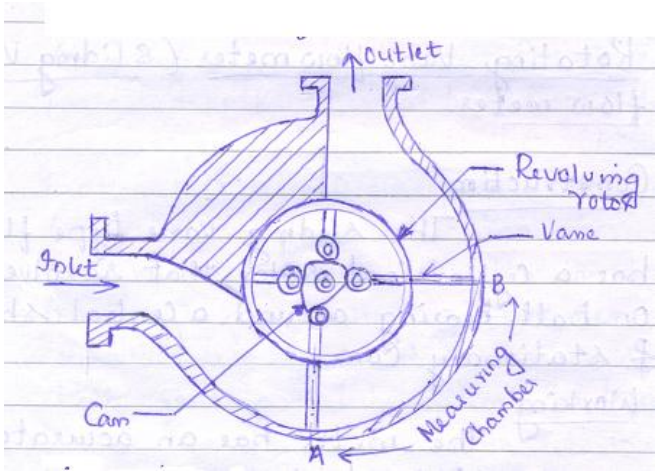
1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

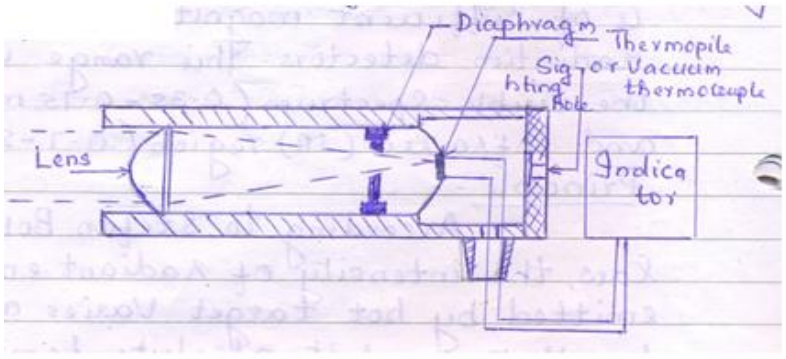
Q No.		Answer	Marking scheme
1 a		**Attempt any THREE of the following**	**12**
1a	i	**1)Accuracy:** It is the instruments ability to indicate or record the true value of the variable being measured. **2) Precision:** It is the degree of exactness for which an instrument is designed to perform **3)Sensitivity:** It is the smallest change in the value of the measured variable to which an instrument responds. **4) Repeatability:** It is the closeness of agreement among a number of consecutive measurements of the output for the same value of input under the same operating conditions, approaching the measurement from the same direction.	1 mark each
1a	ii	**Difference between variable head meter and variable area meter:** **(any three)**	1 mark each

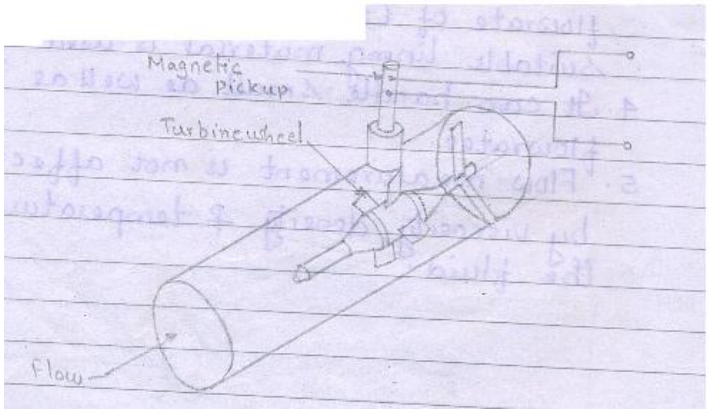
Variable head meter	**Variable area meter**
1. Area of flow is constant and pressure drop varies with flow rate	Pressure drop is constant and area of flow varies with flow rate
2. Cannot give volumetric flow rate directly	Can give volumetric flow rate directly
3. Relatively cheap	costly
4. Simple in construction	complex

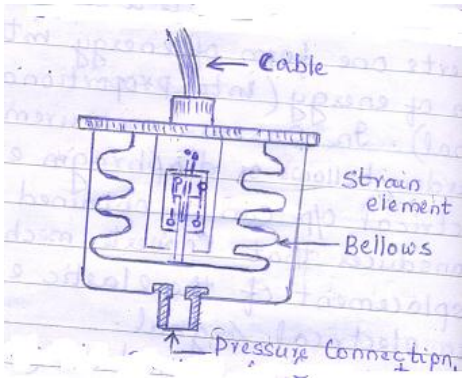
		5. Need straight pipe before and after the meter | Does not need	
		Eg for variable head meter(any one) : Orificemeter, venturimeter	½
		Eg for variable area meter : Rotameter	½
1a	iii	**Different methods of direct level measurement** Sight glass method, float type level indicator **Sight glass method for level measurement:**  Sight glass instrument consists of graduated tube of toughened glass which is connected to the exterior of the tank at the bottom. The liquid level in the sight glass matches the level of liquid in the tank. As the liquid level in the tank rises and falls, the liquid level in the sight glass also rises and falls accordingly. Thus by measuring the level in the sight glass, the level of the liquid in the tank is measured. OR **Float type liquid level measurement:** **Diagram**	1 3

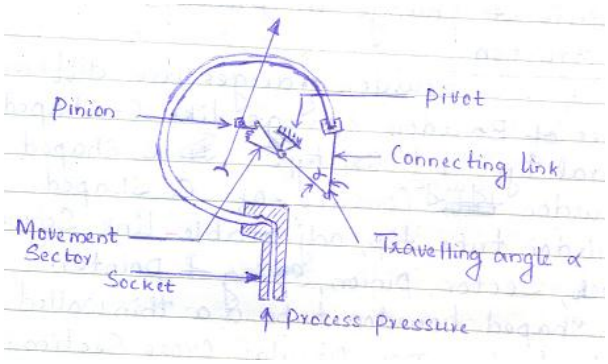
		 **Explanation:** Float operated level indicator is used to measure liquid levels in a tank in which a float rests on the surface of liquid and follows the changing level of liquid. The float is made of corrosion resisting material (such as stainless steel) and rests on liquid level surface between two grids to avoid error due to turbulence The movement of the float is transmitted to a pointer through a suitable mechanism which indicates the level on a calibrated scale	
1a	iv	**Servo operation** The operation in which the purpose of control system is to make the process to follow the changes in set point as closely as possible (no change in load but set point is changing) is termed as servo operations **Eg:** Varying the temperature of a reactor according to a prescribed time-temperature pattern, processing of metals in which the set point is changed with certain time schedule so as to anneal the metal at different temperatures. **Regulator operation:**	1 1

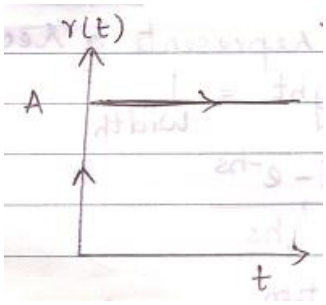
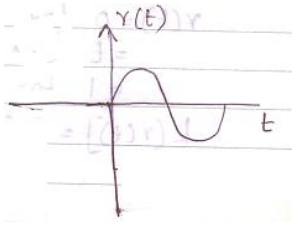
		The operation in which the purpose of control system is to maintain the controlled variable at set point in spite of changes in load is called regulator operation. **Eg :** continuous chemical process in which the flow of process material is maintained at a constant value.	1 1
1b		**Attempt any ONE of the following**	**06**
1b	i	**Principle of positive displacement flow meter:** These meters have chambers of known volumetric capacity and they are arranged so that when one chamber is being filled, the other is being emptied. For measuring the total flow over a certain period, the fluid is continuously filled and emptied from the chamber and then the number of times the chamber is being filled and emptied in that period is counted which when multiplied by the volumetric capacity of the chamber gives the total flow. **Rotating vanemeter** **Diagram:**  **Working:** It consists of a cylindrical rotor that revolves on ball bearings around a	2 2

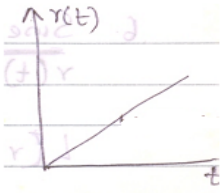
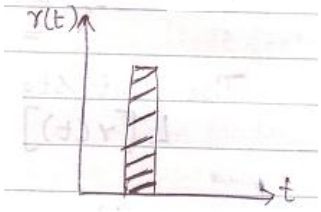
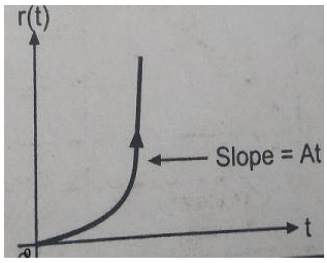
		central shaft and stationary cam, as shown in Fig. The liquid entering the inlet revolves the rotor and the vanes around a cam causing the vanes to move radially. The vane nearest to the inlet port begins to move outward and becomes fully extended at point A as shown. The vane ahead at point B is already fully extended and thus a measuring chamber of known volume is formed between the two vanes. A continuous series of chambers at the rate of four per revolution is formed which delivers the flow at the outlet.	2
1b	ii	**Radiation pyrometer** **Diagram**  **Construction:** It consists of a lens, diaphragm, radiation receiving element, sighting hole and recorder or indicator. Lens is used to concentrate the radiant energy from the hot source on the diaphragm and on the thermopile. Sighting glasses enable the proper line of sight and proper focus to be established. **Working:** Radiation of all possible wave lengths from a hot body is focused by the lens on the radiation receiving element. When thermopile or vacuum	2 1.5 1.5

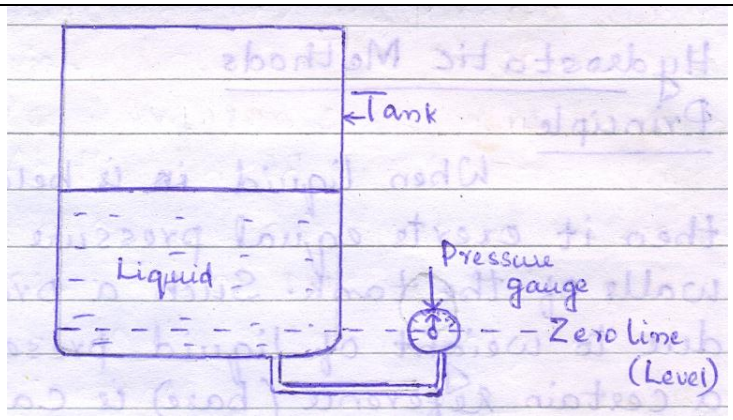
		thermocouple is used as radiation receiving element, the radiant energy from the target is focused in blackened measuring junction. Due to absorption of radiant energy, the measuring junction temperature rises. According to Seebeck effect, emf is developed between output leads which are proportional to temperature difference between measuring and reference junction. The emf developed is calibrated in terms of target temperature by using either a voltmeter or Wheatstone bridge circuit. **Application (Any one):** 1) Used in corrosive environments 2) Used for measuring temperature of moving objects 3) Measuring temperature of targets which are not easily accessible.	1
2		**Attempt any FOUR of the following**	**16**
2	a	**Turbine flow meter:** **Diagram**  **Working** The flow of liquid past the wheel causes the wheel to rotate at a rate which is proportional to the velocity of the fluid. This is achieved by fabricating the turbine blades from a ferromagnetic material and placing a permanent magnet	2

		and coil inside the meter housing. A voltage pulse is induced in the coil as each blade on the turbine wheel moves past it and these pulses are measured by a pulse counter.	2
2	b	**Strain gauge:** **Diagram:**  **Working** As the pressure acting against the bellows changes, bellows get compressed or expanded that causes straining of the strain elements. Strain element being a resistance element, its electrical resistance changes with strain produced. This change in resistance causes deflection of galvanometer in the bridge circuit. The galvanometer can be calibrated in terms of pressure. It can be used for absolute, gauge and differential pressure measurement. ***Due consideration should be given for any other type of strain gauge transducer***	2 2
2	c	**Different elements of Instruments:** 1. Primary element: It is the part of the instrument that first utilizes energy from the measured medium to produce a condition representing the value of the measured variable.	

		2. Secondary element: It converts the condition produced by the primary element into a condition useful to the function of the instrument. 3. Manipulation element: It performs the given operation on the condition produced by the secondary element. 4. Functioning element: It is the part of the instrument used for transmitting, signaling, registering, indicating or recording. Eg. Bourdon tube pressure gauge. In this case the bourdon tube acts as the primary element, mechanical linkage as secondary element, gearing arrangement as the manipulating element and scale & pointer as the final functional element.	3 1
2	d	**C type Bourdon tube** **Diagram**  **Advantages:** 1) Low cost 2) Simple construction 3) Wide pressure range 4) High accuracy in relation with low cost **Disadvantages:** 1) Low spring gradient	2 ½ mark each for any two points

		2) Susceptible to shock and vibration 3) Susceptible to hysteresis	½ mark each for any two points
2	e	$^0K = [5/9 (^0F - 32)] + 273$ (i) $77^0F = 298$ K (ii) $113^0F = 318K$	 2 2
2	f	**Inputs for control systems:** Input signals to control systems that are used to analyze systems called standard test inputs can be of the following types. i) Step input: It is the sudden application of the input at a specified time.  ii)Sinusoidal: It is the input which oscillates with a constant amplitude and frequency.  iii)Ramp **:** It is a constant rate of change in input ie, gradual application of	1 mark each for any four

		input.  iv)Impulse: It is the input applied for a short duration of time of very high amplitude.  v. Parabolic input: this is the input which is one degree faster than ramp input  	
3		**Attempt any FOUR of the following**	**16**
3	a	**Pressure gauge method :** **Diagram:**	

		 **Description:** When liquid is held in a tank, then it exerts equal pressure on the walls of the tank. Such a pressure is due to the weight of liquid present above a certain reference point or base and is called hydrostatic head or pressure. A pressure gauge is located at the zero level of the liquid in the tank. Any rise in level causes an increase in pressure, which can be measured by the gauge. The gauge scale is marked in units of level measurement.	2 2
3	b	**Applications of** **(i) Ultrasonic flow meter (Any two)** a) Oil and gas industry. b) Water and wastewater. c) Power plant. d) Chemical industry. e) Food and beverage industry. f) Pharmaceutical, metals and mining, and pulp and paper. **(ii) Turbine flow meter (Any two)** a) For Military Application. b) Used in blending system for the Petroleum industry.	1 mark each 1 mark each

		c) Used in aerospace and airborne application for energy-fuel and cryogenic flow measurements.	
3	c	**Air to open control valve:**  They are control valves operated through pneumatic actuators. It is designed in such a way that if the air supply fails, the control valve will be fully closed for safety requirement of the process. **Air to close control valve:** It is designed in such a way that if the air supply fails, the control valve will be fully open for safety requirement of the process.  **Control valve used in hazardous system:** The valve used to control hazardous processes should be completely shut off in case of air failure. Hence air to open control valve is recommended.	1.5 1.5 1
3	d	**Seebeck effect:** Seebeck discovered that when there is temperature difference between two junctions of thermocouple, an emf is developed between the junctions. This emf causes electric current to flow through thermocouple circuit. This is called	2

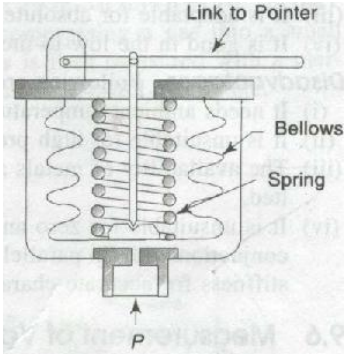
thermoelectric effect by which thermal energy is converted to electrical energy.

Thermocouple with temperature range (any two)

Thermcouple type	Material used	Temperature range
B	Platinum and Rhodium	0 to 1860^{0}C
E	Chromel and Constantan	-196 ^{0}C to 900^{0}C
J	Iron and Constantan	-196^{0}C to 760^{0}C
K	Chromel and Alumel	-190^{0}C to 1370^{0}C
S	Platinum-Rhodium and Platinum	-18^{0}C to 1760^{0}C
T	Rhodium –Copper and Constantan	-190^{0}C to 399 ^{0}C

1 mark each

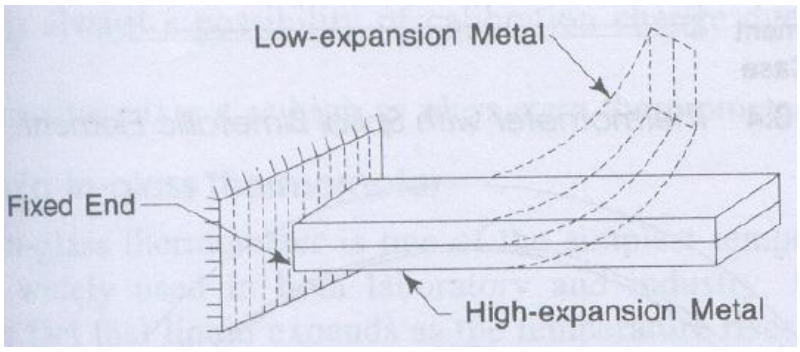
3 e **Bellows used for measuring differential pressure:**

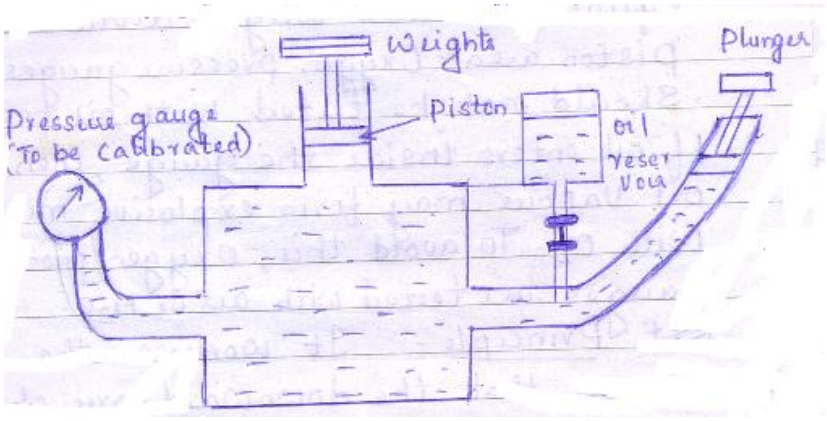


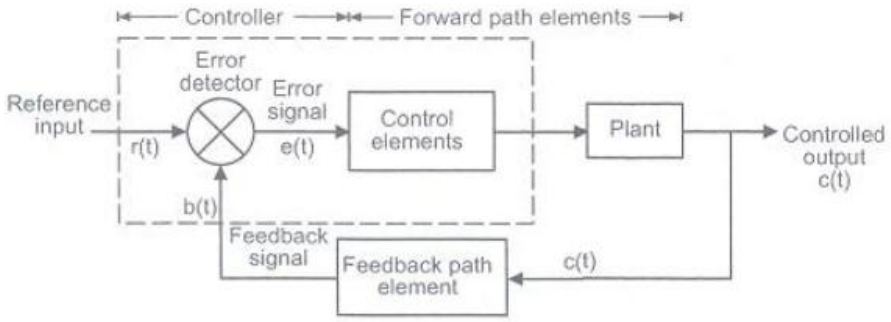
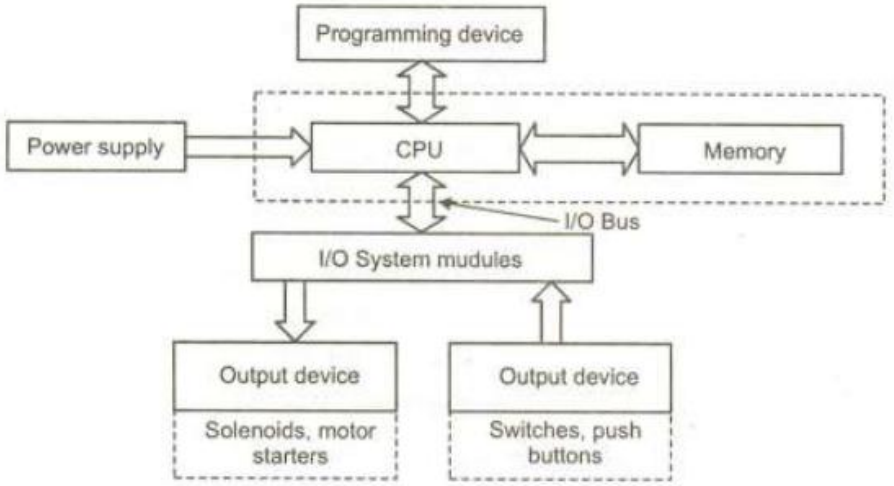
When bellows are used as differential pressure gauge, one of the pressure is fed inside the bellows , while the other is fed outside it so that the differential pressure acts across the bellows. The movement of free end of bellows represents differential pressure.

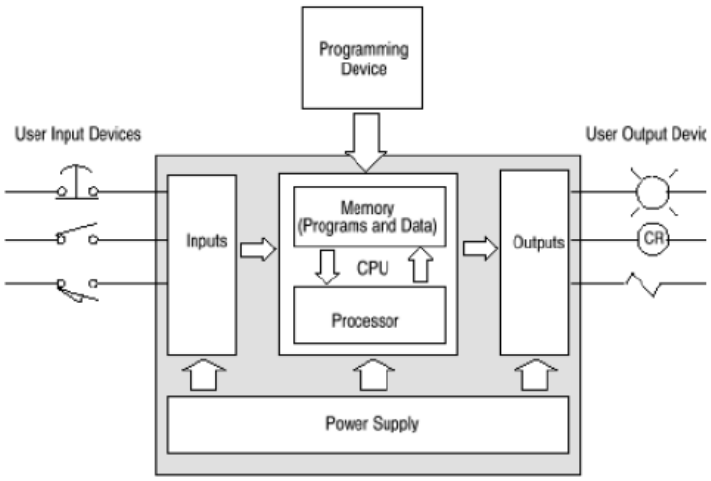
4

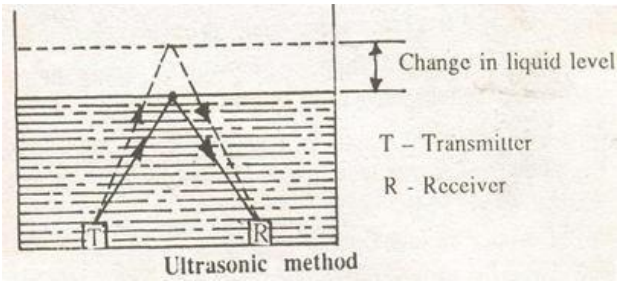
3 f **Features of distributed control system(Any four):** 1 mark each

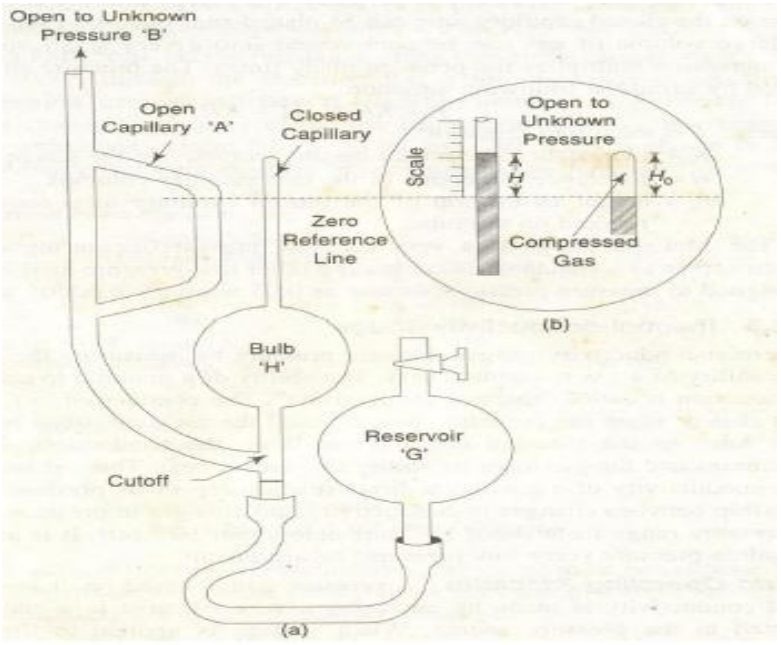
		i. Monitor & manipulate the process ii. Retrieve historical data (batch history is required to facilitate display & analysis of key characteristics within a batch between batches of similar types) iii. Configure the system iv. Develop control programs v. Diagnose system failures.	
4 a		**Attempt any THREE of the following**	**12**
4a	i	**Bimetallic thermometer:** **Diagram:**  **Working:** Bimetallic strip consists of two strips of metal such as invar and brass welded together, each strip made from a metal having a different coefficient of thermal expansion. Whenever the welded strip is heated, the two metals change length in accordance with their individual rates of thermal expansion. The two metals expand to different lengths as the temperature rises. This forces the bimetallic strip to bend towards the side with low coefficient of thermal expansion as shown in Fig above. If one end of the bimetallic strip is fixed so that it cannot move, the distance the other end bends is directly proportional to the square of the length of the metal strip, as well as to the total change in temperature, and	2 2

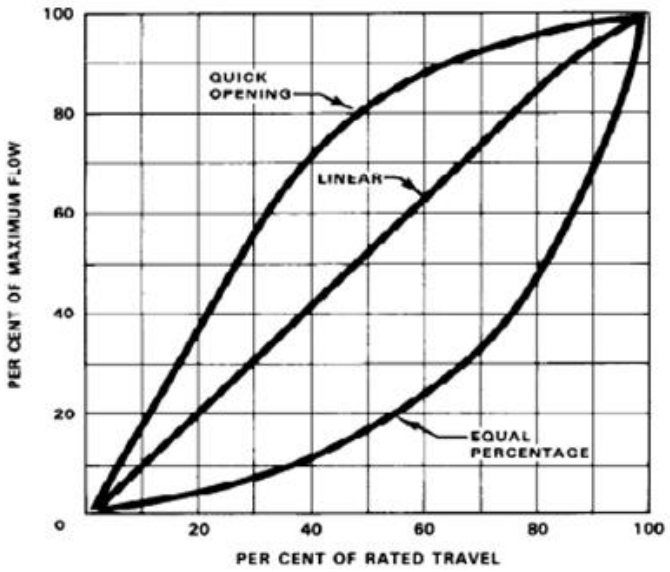
		is inversely proportional to the thickness of the metal. The movement of the bimetallic strip is utilized to deflect a pointer over a calibrated scale.	
4a	ii	**Calibration of pressure gauge by dead weight tester:**  It consists of a very accurately machined, bored and finished piston which is inserted into a close-fitting cylinder. The cross sectional areas of both the piston and the cylinder are known. At the top of the piston is provided a platform on which the standard weight, of known accuracy, can be placed An oil reservoir with a check valve at its bottom is also provided. The oil from the reservoir can be sucked by a displacement pump on its upward stroke. For calibration purpose, first a known (calculated) weight is placed on the platform and the fluid pressure is applied on the other end of the piston until enough force is developed to lift the piston-weight combination and the piston floats freely within the cylinder when the fluid gauge pressure equals the dead weight divided by the piston area.	4
4a	iii	**Block diagram of closed loop control system:**	4

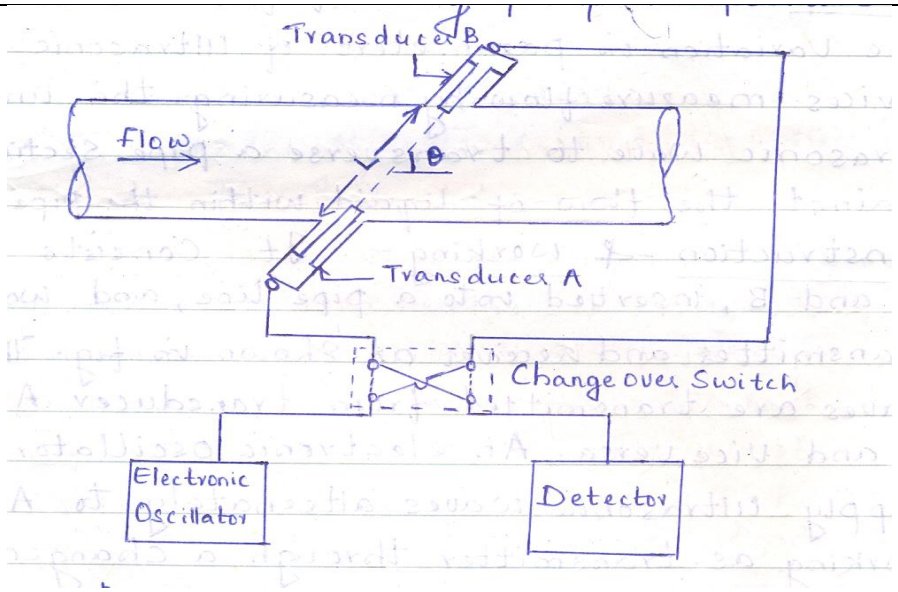
		 r(t) = Reference input, e(t) = Error or actuating signal, b(t) = Feedback system.	
4a	iv	**Block diagram of programmable logic controller:**  **OR**	4



4b		**Attempt any ONE of the following**	**06**
4b	i	**Solid level measurement:** Ultrasonic Level measurement:  **Construction and working:** Transmitter is the source of ultrasonic oscillations such as piezo-element like Quartz, which is positioned at the top or bottom of the vessel. The ultrasonic waves from the transmitter reach the material surface from where they get reflected back and these reflected waves are received by the receiver. The time interval from the instant of an emission of the waves to the reception of the reflected rays is measured, which varies with liquid level.	3 3

		(Due consideration should be given for Capacitance method and radioactive method of solid level measurement)	
4b	ii	**Mc-Leod gauge:** **Diagram:**  **Working:** To operate the gauge, the piston is first withdrawn, causing the level of mercury in the lower part of the gauge to fall below the level of the junction between the two tubes. The unknown pressure source is connected to the gauge from where it also flows and fills the bulb and capillary. Next, the piston is pushed in, moving the mercury level up to block the junction. At this stage,, the fluid in the capillary and the bulb is at pressure P. Further movement of the piston compresses the fluid in the tube and the mercury level is raised till it reaches the zero reference point in R. Measurement of the height above the mercury column in the capillary allows the calculation of the compressed	3 3

		volume of the fluid. The expression for calculating the unknown pressure is $P = A\rho gy^2 / V$ Where A is capillary area ρ is density of fluid y is height above the mercury column in capillary.	
5		**Attempt any FOUR of the following**	**16**
5	a	**Valve Characteristics:** **Definition** The relation between stem position, plug position and rate of flow is known as valve characteristics. **Diagram:**  	1 3
5	b	**Ultrasonic flow meter** : **Diagram** :	



2

Working :

It consist of two transducers , A and B , inserted into a pipe line, and working both as transmitter and receiver. The ultrasonic waves are transmitted from transducer A to transducer B and vice versa. An electronic oscillator is connected to supply ultrasonic waves alternately to A or B which is working as transmitter through a change over switch , when the detector is connected simultaneously to B or A which is working as receiver. The detector measure the transit time from upstream to downstream transducer and vice versa.

The time T_{AB} for ultrasonic wave to travel from transducer A to transducer B is given by $T_{AB} = L/(C+V\cos\theta)$ 2

The time T_{BA} for ultrasonic wave to travel from transducer B to transducer A is given by $T_{BA} = L/(C-V\cos\theta)$ Where

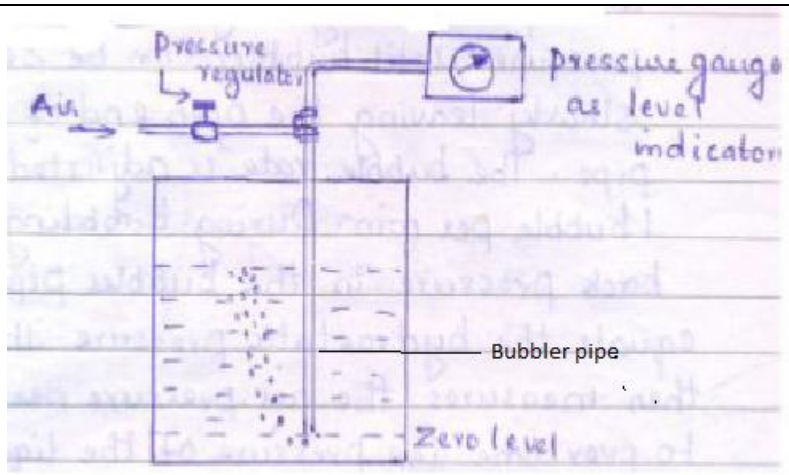
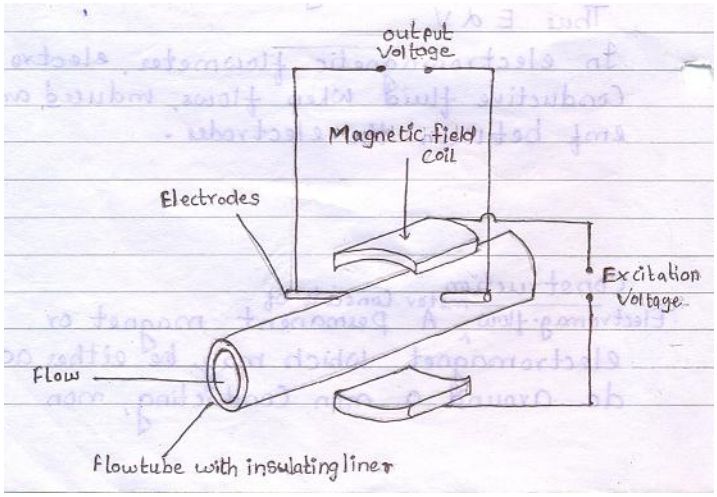
L – Acoustic path length between A & B

C – Velocity of sound in fluid.

θ – Angle of path with respect to pipe axis.

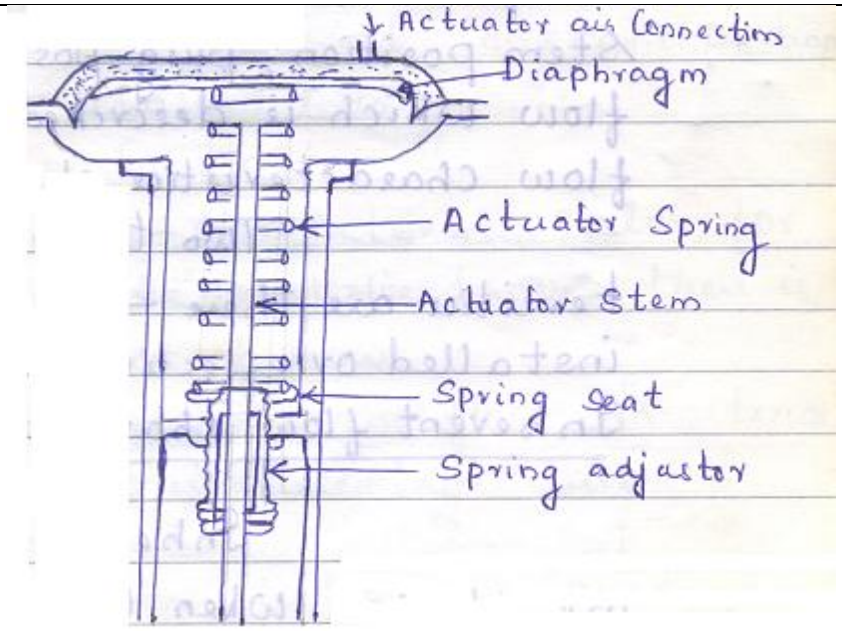
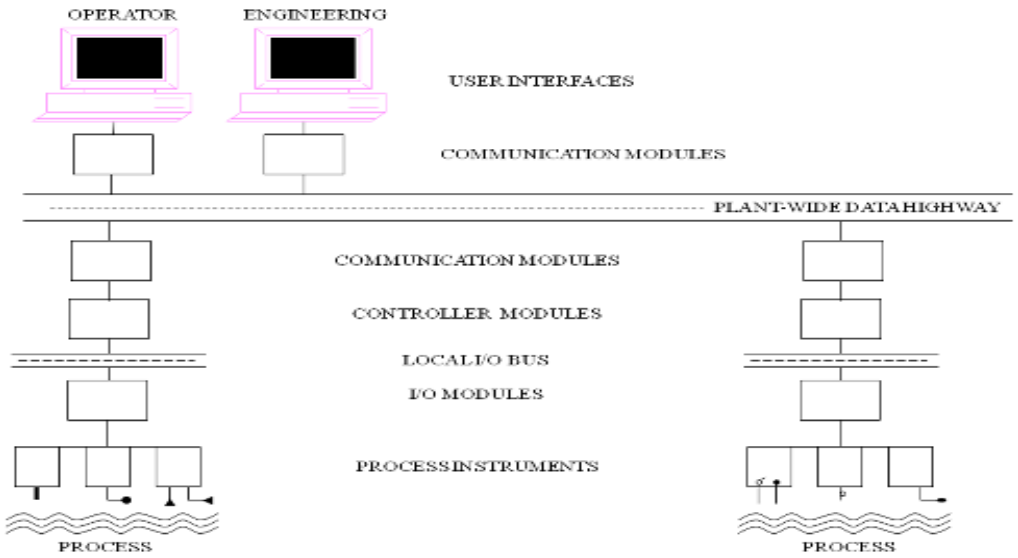
		V – Velocity of fluid in pipe. $V = \Delta TC/2LCos\theta$ where $\Delta T = T_{BA} - T_{AB}$ Since this type of flow meter relies upon an ultrasonic signal traversing across the pipe, the liquid must be relatively free of solids and air bubbles.	
5	c	**Factors to be considered for valve selection(any four) :** The basic steps in control valve selection are 1. The first step in control valve selection involves collecting all relevant data and completing the ISA Form S20.50. The piping size must be set prior to valve sizing, and determining the supply pressure may require specifying a pump 2. The size of the valve is required; select the smallest valve Cv that satisfies the maximum Cv requirement at 90% opening. While performing these calculations, checks should be made regarding flashing, cavitation, sonic flow and Reynolds number to ensure that the proper equation and correction factors are used. As many difficulties occur due to oversized valves as to undersized valves. Adding lots of "safety factors" will result in a valve that is nearly closed during normal operation and has poor rangeability. 3. The trim characteristic is selected to provide good performance; goals are usually linear control loop behaviour along with acceptable rangeability. 4. The valve body can be selected. The valve size is either equal to the pipe size or slightly less, for example, a 3-inch pipe with a 2-inch globe valve body. When the valve size is smaller than the process piping, an inlet reducer and outlet expander are required to make connections to the process piping. 5. The actuator is now selected to provide sufficient force to position the stem and plug.	1 mark each

		6. Finally, auxiliaries can be added to enhance performance. A booster can be increase the volume of the pneumatic signal for long pneumatic lines and large actuators. A positioner can be applied for slow feedback loops with large valves or valves with high actuator force or friction. A hand wheel is needed if manual operation of the valve is expected.	
5	d	**Application of PLC:** 1) PLC can be a vital part of industrial automation as it produces on/off voltage outputs to actuate elements such as electric motors, solenoids etc. 2) It can also be used in sequential controllers used for periodical on/off of fans, heaters and light switches. **Application Of DCS:** 1) DCS are designed for continuous process where the control signal is analog rather than discrete. 2) It is a powerful integrated control system having capabilities such as, data acquisition, advanced process control and batch control capabilities for various industrial environments such as cement factory, oil refinery, power plant etc.	1 mark each 1 mark each
5	e	**Air purge method:** To make level measurement, the air supply is adjusted so that the pressure is slightly higher than the pressure due to the height of the liquid and bubbles can be seen slowly leaving the open end of the pipe. The bubble rate is adjusted as 1 bubble / minute. During bubbling, the back pressure in the bubbler pipe exactly equals the hydrostatic pressure. The gauge then measures the air pressure needed to overcome the pressure of the liquid	4

			
5	f	**Working of electro magnetic flow meter:**  As the conducting fluid flows through the pipe, due to the magnetic field around the pipe, an emf is induced between the electrodes. The induced emf is given by E=Blv where E-emf l-Length of conductor B-Magnetic flux density	4

		v-Velocity of conductor This emf induced is proportional to the velocity of the conductor. As the flow rate varies, velocity of fluid changes and hence the induced emf changes.	
6		**Attempt any TWO of the following**	**16**
6	a	**Different control actions** The 4 basic control action are, 1. On-Off or Two position control action: In ON/OFF control action, the output has only two states -fully ON or fully OFF. It operates on the manipulated variable only when the measured variable crosses the set point. m= 0 , for e > 0 m = 100%, for e < 0 m – output , e - error 2. Proportional (P)controller: In proportional controller, the output of the controller is proportional to error. $m=K_P e$ Kp – proportional gain e - error 3.Integral (I)or reset action: In integral control action, value of controller output is the accumulated error over an extended period of time. The controller output can have nonzero value when the error signal is zero. $m = \frac{1}{T_i}\int_0^t edt$ + m(0) Ti – integral time e – error	2 marks each

		m(0) - controller output for zero error. 4. Derivative (D)or Rate controller: $M = T_d\ de/dt$ Td – derivative time de/dt – rate of change of error. The derivative control action responds to the rate at which the error is changing. makes the above expression equal to zero.	
6	b	**Function of valve actuator:** it is that portion of the valve that responds to the applied signal and results in the movement of the stem due to which the flow rate of fluid changes. It consists of diaphragm, stem and diaphragm returning spring **Working of spring diaphragm actuator:** It consists of a pressure tight housing sealed by a flexible diaphragm, stem and diaphragm returning spring. Signal air pressure from the controller is applied to upper diaphragm case, that exerts force on the diaphragm and the actuator assrmbly.by selecting proper spring rate or stiffness, desired stem displacement can be obtained for any given input signal. The diaphragm is made of neoprene or any other synthetic elastic element.	2 3

			3
6	c	**Distributed control system:** **Block diagram:**  **Description:**	4

		In DCS equipment is separated in functional area and is installed in different work areas of a process plant. The plant operator monitors and manipulates the set-points of the process parameter from central control room. Controlling portion of the DCS, distributed at various location performs following two function at each location. 1. Measurement of analog variable and discrete inputs 2. Generation of output signals to actuators that can change process condition In Figure above the operator console in the control room is connected through a data highway to several distributed system components. A DCS consist of the following modules: 1 Operator stations that use microprocessor based CRT display and keyboard communication with control device and displays 2 Remote multifunction microprocessor based controllers (PLCs) 3 A digital data link (data highway) that connects the multifunction controllers with the central operator stations. The first priority of DCS is to provide operator interfacing and real time process control. DCS has flexibility of implementation of sequential control and integration among the various types of control.	4