National Exams December 2017

04-Agric-A5, Principles of Instrumentation

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is an OPEN BOOK EXAM.
Any non-communicating calculator is permitted.

3. Questions 1, 2 and any other THREE (3) questions constitute a complete exam paper. Only questions 1, 2 and the first THREE (3) other questions as they appear in your answer book will be marked.

4. All questions are of equal value.

Marking Scheme

The paper totals 100 marks. Questions 1 and 2 are compulsory and 3 of questions 4-7 must be attempted. **Note:** the marking scheme is indicated on the exam paper.

1. 20 Marks, (a-j) 2 each.
2. 20 marks, (a-j) 2 each.
3. 20 marks, (a) 5 marks, (b) 5 marks, (c) 5 marks, (d) 5 marks.
4. 20 marks, (a) 6 marks, (b) 4 marks, (c) 3 marks, (d) 4 marks, (e) 3 marks.
5. 20 marks, (a) 5 marks, (b) 5 marks, (c) 5 marks, (d) 5 marks.
6. 20 marks, (a) 6 marks, (b) 2 marks, (c) 3 marks, (d) 6 marks (e) 3 marks,
7. 20 marks, (a) 4 marks, (b) 6 marks, (c) 5 marks, (d) 5 marks.

Question 1. (20 marks)(You must answer this question. Each part is worth 2 marks.)

Answer the following short answer questions very briefly. Point form, graphs or sketches may be used as appropriate.

a) (2 marks) Why is the RMS error of a calibration more meaningful than an R^2 value?

b) (2 marks) Why is a three point calibration of an instrument often required?

c) (2 marks) Why can hysteresis in a sensor make it useless as a measuring device?

d) (2 marks) What determines the smallest value of a variable that can be reliably measured?

e) (2 marks) How long would you have to wait before the reading from a sensor can be considered to be stable?

f) (2 marks) Which is more important in a measurement system, accuracy or precision? Explain very briefly.

g) (2 marks) What are the zero and span of a measurement system?

h) (2 marks) How is the phase rule from thermodynamics used in the making of calibration standards?

i) (2 marks) What parameters describe the dynamic response of a mass sensor?

j) (2 marks) Why should a calibration be repeated several times?

Question 2. (20 marks)(You must answer this question. Each part is worth 2 marks.)

Answer the following short answer questions very briefly. Point form, graphs or sketches may be used as appropriate.

a) (2 marks) How can data be transferred without a direct electrical between a sensor and a data acquisition system?

b) (2 marks) Why can noise never be completely removed from a measurement system?

c) (2 marks) What type of filter is required to reduce aliasing errors?

d) (2 marks) How can electrical interference be reduced in an instrument system?

e) (2 marks) Why is the first amplifier stage the most critical in measuring a low level signal?

f) (2 marks) What is a reference electrode?

g) (2 marks) Why do phototransistors give a higher signal than photodiodes?

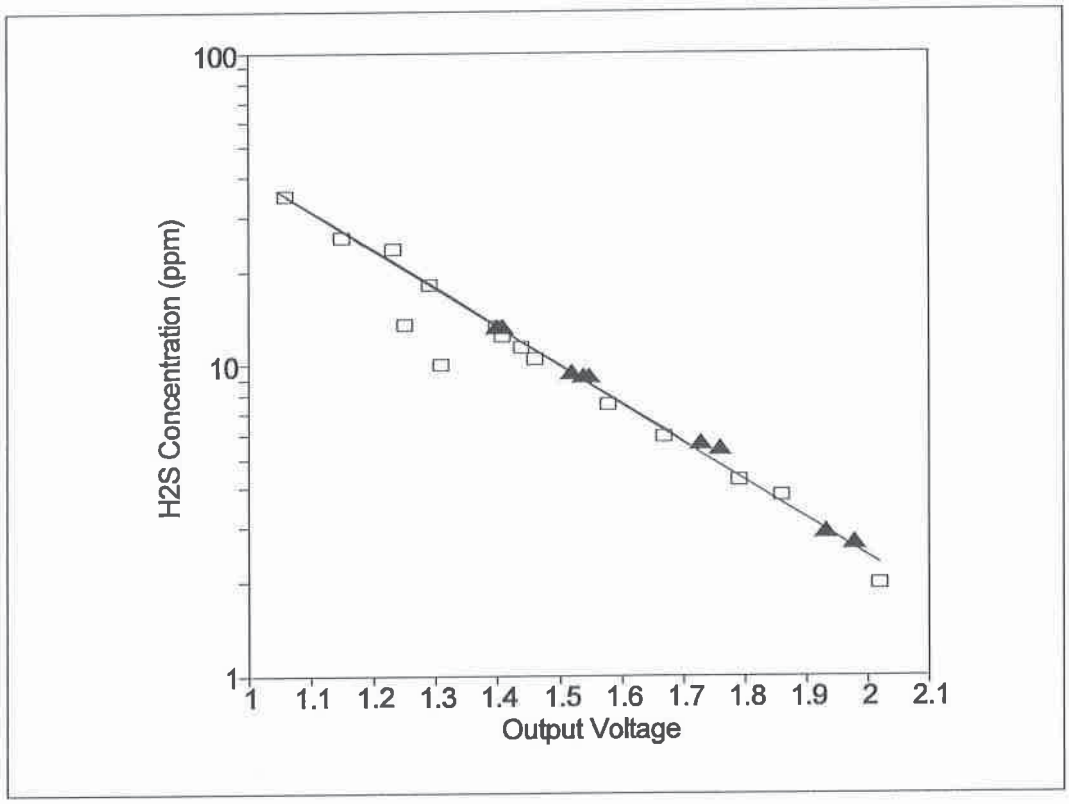
h) (2 marks) What is the source of self heating errors in some temperature sensors?

i) (2 marks) What is 'shot' noise?

j) (2 marks) Why should derivatives be avoided in measurement calculations?

Question 3. (20 marks)(You only have to do three questions from questions 3 to 7.)

Hydrogen sulfide (H_2S) is a very toxic gas which has killed farmers during manure transfer operations. One of the important sensors uses a heated metal oxide element which changes resistance when exposed to H_2S.



a) (5 Marks) Where in the calibration range is the sensor most sensitive to H_2S?

b) (5 marks) On the graph are two outliers (points away from the best fit line). How should you deal with these points? Explain your answer?

c) (5 marks) If the response speed of the instrument is slower when going from a high concentration to a lower one, what should be done to insure a correct reading?

d) (5 marks) If your company will sell this type of sensor, comment on the liability issues which may arise.

Question 4. (20 marks)(You only have to do three questions from questions 3 to 7.)

The LM741 is perhaps the most widely used operational amplifier. The following characteristics represent the LM741 and the LF13741, a JFET amplifier. Both amplifiers are functionally equivalent but perform differently.

	LM741	LF13741	Units
Open loop voltage gain	200	100	V/mV
Input impedance	$2x10^{6}$	$5x10^{11}$	Ohms
Input bias current	$8x10^{-8}$	$5x10^{-11}$	Amps
Input offset voltage	1	5	mV

a) (6 marks) Design a first order low pass filter with a DC gain of 5 and a time constant of 60 seconds. Justify your choice of amplifier. What is the input impedance of the filter you designed?

b) (4 marks) List several applications of low pass filters in the design of measuring instruments and explain them very briefly.

c) (3 marks) Why are high input impedances desirable for any amplifier of filter application?

d) (4 marks) Explain the disadvantages of using high value (Ohms not $) resistors

e) (3 marks) Why must the input bias currents be returned to ground? This is particularly important in non-inverting amplifier configurations.

Question 5. (20 marks)(You only have to do three questions from questions 3 to 7.)

Many flow meters such as orifice plates, venturi meters and flumes are based on Bernoulli's equation. This equation can be reduced to:

$$Q = k\sqrt{\Delta p}$$

Where Q is the flow rate, Δp is the measured pressure drop and k is a constant depending on the design of the flow meter.

a) (5 marks) What parameters are included in k?

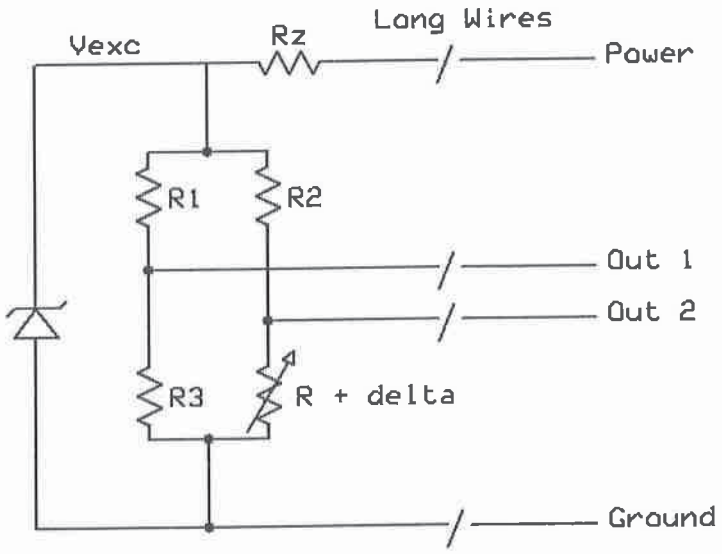
b) (5 marks) What assumptions are made when this type of flow meter is used?

c) (5 marks) Explain why it is better to use a differential pressure gage rather than subtract two absolute pressure readings.

c) (5 marks) Why does an average Δp reading not represent the average flow rate?

Question 6. (20 marks)(You only have to do three questions from questions 3 to 7.)

The Wheatstone bridge is a circuit which is excellent for measuring small resistance changes. As shown in the figure, the bridge is setup to measure a single changing resistance. This may be a single strain gage or an RTD temperature sensor.



a) (6 marks) Assuming that all of the bridge resistors are the same (R1 = R2 = R3 = R), develop an equation giving the voltage difference between Out 1 and Out 2.

b) (2 marks) If long wires are used (as shown) why should this entire circuit be located very close to the sensing resistor?

c) (3 marks) What is the purpose of the Zener diode?

d) (6 marks) In a strain gage application, the use of two strain gages in the bridge can compensate for temperature changes. Show how this works.

e (3 marks) In choosing the excitation voltage, Vexc, what is the tradeoff between a higher Vexc and a lower Vexc?

Question 7. (20 marks)(You only have to do three questions from questions 3 to 7.)

There are two types of electrochemical sensors, potentiometric and amperometric. A pH meter is an example of a potentiometric sensor. The pH electrode consists of a glass membrane with one side exposed to the test solution and the other to a reference solution. Hydrogen ions are exchanged at the glass surfaces and the resulting voltage difference is measured.

a) (4 marks) Why does the input impedance of a pH meter have to be extremely high?

b) (6 marks) The electrical contacts to the two solutions is made using reference electrodes. What is a reference electrode and how is it constructed?

Oxygen sensors are amperometric, where the current flowing through the sensor is measured. Here oxygen diffuses through a membrane and is completely reduced at the cathode surface.

c) (5 marks) Why is the response of this type of oxygen sensor linear with respect to the oxygen concentration?

Fouling is a serious problem with electrochemical sensors.

d) (5 marks) What is electrode fouling and how does it affect both of the above sensor types?