EAS327 "Environmental Instrumentation" <u>Mid-term</u> 8 Feb, 2005

<u>Professor</u>: J.D. Wilson <u>Time available</u>: 80 mins <u>Value</u>: 20%

Instructions: Closed book exam. Please record your answers in the exam booklet. Pertinent data and diagrams are at the back, and should be read before answering any questions.

Multi-choice (20 x $\frac{1}{2}$% → 10%)

1. In the context of the simplest environmental instruments we have to do with "d.c. circuits" (slowly varying signals). To be sure of the absence of "noise" in such a circuit, one should inspect the signal with a/n ____

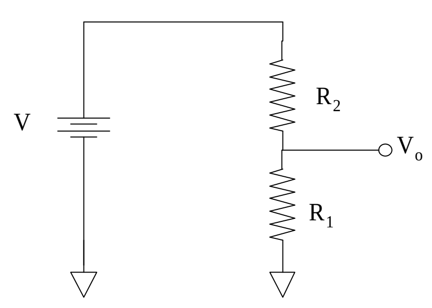
   (a) multimeter
   (b) oscilloscope ✓✓
   (c) chart recorder
   (d) data-logger
   (e) grounded receiver

2. To connect an oscilloscope (lo = power-line ground) to display a potential difference between two points in a d.c. circuit, which of the steps below would be wrong?

   (a) ascertain that the normal performance of the circuit will not be disrupted by pulling one of the two circuit points to p.l.g.
   (b) adjust the zero on the scope
   (c) adjust the full-scale-range on the scope to a suitable value for the expected measurement
   (d) adjust the scope triggering to "auto"
   (e) select a.c. coupling ✓✓

3. If $V_o = 2$ V, $R_1 = 10$ KΩ and $R_2 = 5$ KΩ, then the supply voltage V is ____ volts

   (a) 5
   (b) 3 ✓✓
   (c) 2
   (d) 1.33
   (e) 0.66



4. You are given two points on the resistance-temperature curve of a thermistor: (10 C, 75 KΩ) and (20 C, 50 KΩ). Between these points your best guess for the "slope" dR/dT of the resistance-temperature curve is ____

   (a) 25 KΩ C^{-1}
   (b) – 25 KΩ C^{-1}
   (c) 2.5 KΩ C^{-1}
   (d) – 2.5 KΩ C^{-1} ✓✓
   (e) zero

5. If the resistance measured between a voltage-receiver ground and its inputs is large and equal for *both* inputs ('hi' and 'lo', also sometimes labelled V^+, V^-), then the receiver is called ____

   (a) hi gain
   (b) differential ✓✓
   (c) single-ended
   (d) grounded
   (e) floating

6. Suppose a data-logger displays a number N representing the voltage $(V^+ - V^-)$ across its two input terminals, and that it can be assumed that the logger is "linear," ie., that $N = \alpha(V^+ - V^-) + \beta$. Furthermore, suppose the Full Scale Range (FSR) of the logger is ± 10 volts. If we measure a reading N_1 when $(V^+ - V^-) = 10.0$ volts, and a reading N_2 when $(V^+ - V^-) = -10.0$ volts, then the quantity $(N_1 - N_2)/20.0$ is ____

   (a) the "offset" of the logger, β
   (b) zero
   (c) variable
   (d) the sensitivity, α ✓✓
   (e) none of the above

7. Following on from the above question, the purpose of short-circuiting the input to a data-logger and noting the indicated measurement (N_0) is:

   (a) To remove any common mode voltage
   (b) To assess the necessary full scale range setting
   (c) To ground the input
   (d) To float the input
   (e) To ascertain the "zero reading" or "offset" β ✓✓

8. Generalizing from the case shown, it can be concluded that the charge-voltage ($V-q$) characteristic of a battery is

(a) that of a capacitor
(b) that of a resistor
(c) unlike that of a capacitor ✓✓
(d) Ohm's Law
(e) none of the above

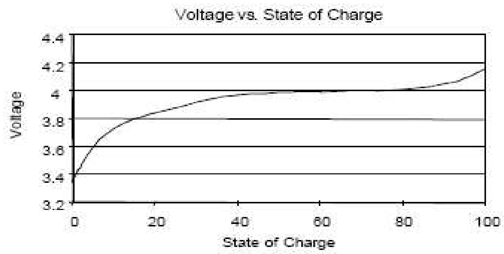


Figure 5. Open Cell Voltage of Lithium Polymer Battery

9. Suppose the fastest fluctuations of a certain signal $x = x(t)$ were characterized by a frequency f_{max} (or equivalently a period $T_{min} = 1/f_{max}$). For an instrument to faithfully measure this signal, its time constant τ (characterizing its step response) would need to satisfy ____

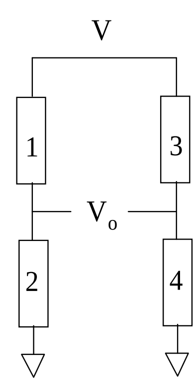
(a) $\tau >> T_{min}$
(b) $\tau << T_{min}$ ✓✓
(c) $\tau = T_{min}$
(d) $1/\tau = f_{max}$
(e) $\tau^2 + 2\tau - 1 = 0$

10. A shaft is rotating 30 times per minute. Its angular frequency in [radians sec^{-1}] is:

(a) 0.5
(b) 180
(c) π ✓✓
(d) 2π
(e) 360

11. Given two identical thermistors R_{1T}, R_{2T} and two identical control resistors R_{1c}, R_{2c}, a differential temperature sensor could be constructed by placing ____ in the full bridge shown

(a) one thermistor in each of slots 1,2
(b) one thermistor in each of slots 3,4
(c) one thermistor in each of slots 1,3
(d) one thermistor in each of slots 2,4
(e) both (c) and (d) would work ✓✓



12. The internal resistance of a particular $V_s = 12$ volt battery is 1Ω. If this battery is connected across an 11Ω load, the power dissipated in the load is ____ Watts

(a) 1/11
(b) 11/12
(c) 1
(d) 11 ✓✓
(e) 12

13. Suppose a symmetric square wave with period T and levels $\pm A$ volts is input to an RC lowpass filter whose time constant $\tau = T$. The voltage V_o across the capacitor (ie. output voltage) will be ____

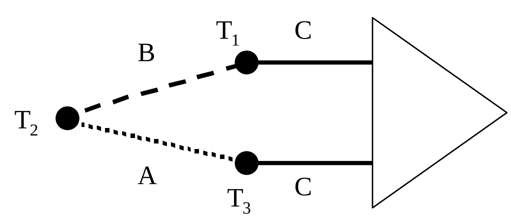
(a) completely steady at $V_o = 0$
(b) a square wave of span $\pm A_o$, with $A_o > A$
(c) a square wave of span $\pm A_o$, with $A_o = A$
(d) a square wave of span $\pm A_o$, with $A_o < A$
(e) a wave centred on $V_o = 0$, of span $\pm A_o$ with $A_o < A$, that lacks the sharp transitions (edges, or 'step changes') of the input wave ✓✓

14. A tank of volume D^3 is kept in a well-stirred condition by a powerful fan, and initially contains a pure gas "A." At $t = 0$ it begins to be flushed by an inflow (volumetric flow rate Q [$\mathrm{m^3\ s^{-1}}$]) of pure gas "B," that displaces (at equal rate) mixed gas through an outlet. The transition of the tank's contents from "pure A" to "pure B" takes place with time constant

(a) $(A - B)/Q$
(b) $A - B$
(c) D^3/Q ✓✓
(d) Q/D^3
(e) $A - BD^3/Q$

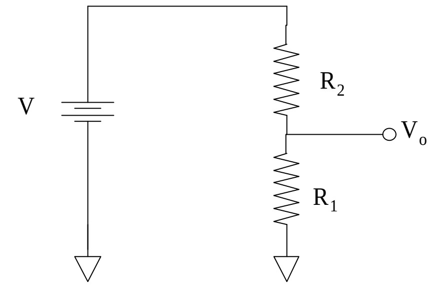
15. If $T_1 = T_2$ then this arrangement measures ____ with a sensitivity determined by metals ____

(a) $|T_1 - T_3|$; (A,B)
(b) $|T_1 - T_3|$; (B,C)
(c) $|T_1 - T_3|$; (A,C) ✓✓
(d) $|T_2 - T_3|$; (A,B)
(e) C; (A,B)



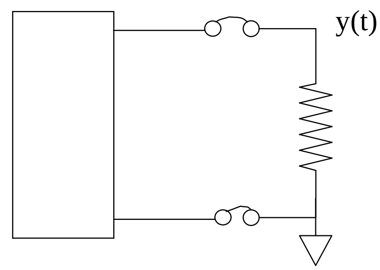
16. A thermistor with characteristic $R(T) = R(T_0)\exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$ is placed as R_2 in the circuit shown, with $R_1 = R(T_0)$. If $T > T_0$ then ____ and ____

(a) $R > R(T_0)$; $V_o > V/2$
(b) $R < R(T_0)$; $V_o > V/2$ ✓✓
(c) $R > R(T_0)$; $V_o < V/2$
(d) $R < R(T_0)$; $V_o < V/2$



17. If the circuit shown is intended to solve the differential equation $\alpha\frac{dy}{dt} = \beta$ (where α, β are constants, and t is time) then the source should be a ____ **The circuit element should have been a capacitor! Question not scored.**

(a) constant current source
(b) constant voltage source
(c) alternating current source
(d) alternating voltage source
(e) current impulse source



18. A linear temperature sensor has sensitivity α [volts K^{-1}] and is input to a voltage receiver having resolution δV [volts]. The resulting temperature resolution (δT) is

(a) α
(b) $\alpha/\delta V$
(c) $\delta V/\alpha$ ✓✓
(d) $1/\delta T$
(e) $\alpha\delta V$

19. If a signal $x = (1, -1, 1, -2, 6)$ then the signal *fluctuation* $x' = x - \overline{x}$ is which series?

(a) 1, -1, 1, -2, 6
(b) 0, 2, 0, 3, -5
(c) 0, 2, 0, -3, 5
(d) 0, 0, 0, 0, 0
(e) 0, -2, 0, -3, 5 ✓✓

20. At steady state and neglecting internal heating and any radiation error, it can be said of the energy balance of a dry thermometer $C\,\Delta T/\Delta t = A\,(Q^* + Q_H + Q_E) + P$ that

(a) the dominant term is Q_H

(b) every term reduces to zero ✓✓

(c) the equation reduces to a balance between $\Delta T/\Delta t$ and Q_H

(d) the equation reduces to a balance between P and Q_H

(e) the equation reduces to a balance between Q^* and Q_H

Short Answer (10 %)

Answer **two** questions from this section. Give diagrams where appropriate. Justify any assumptions or simplifications you make.

1. A thermopile for measuring soil heat flux has been constructed from 20 copper-constantin thermocouples (Seebeck coefficient 40μV C^{-1}) connected in series. All the hot junctions are together at a depth $z = 0.01$ m in the soil, while the cold junctions are at depth $z = 0.05$ m. Calculate the magnitude of the thermopile output voltage, if the soil heat flux density is $Q_G = 20$ W m^{-2}. (Note: you will need to use Fourier's law of heat conduction

$$Q_G = -\kappa \frac{dT}{dz}$$

where κ is the soil conductivity; assume $\kappa = 1.0$ W m^{-1} K^{-1}).

Answer:

$|\Delta T| = 0.8$ C, so magnitude of the output voltage is $|V| = 20$ x 40 x 0.8 μV $= 0.64$ mV (Note: the 'magnitude' of a number is *by definition* its absolute value.)

2. Explain, in terms that should be unambiguous to an intelligent person familiar with the functions of a multimeter, how s/he should proceed in order to determine whether a particular voltage source, having two output terminals labelled (hi, lo), is a floating or a grounded source.

Answer:

- find a convenient conductor whose electrical potential is the same as that of the ground, ie. a point from which there is a low resistance path to ground: for example, the U-ground of an ordinary outlet, or (usually) the steel plumbing
- set the multimeter on its resistance-measuring range, with a full scale setting of 1KΩ or more (10KΩ and 100KΩ acceptable)
- make sure the multimeter is functioning by checking that it reads 'zero' when the probes are touched together
- measure the resistance from the 'lo' to the identified ground point
- if this is not infinity, the source is not a floating source

- conversely, the measured resistance need not be exactly zero even if your source is grounded... the multimeter will see the resistance down the power cable of the device, for example. Thus a measured resistance of up to about 10Ω is compatible with the source being a grounded source

3. Calculate the bulk heat capacity C [J K^{-1}] of a sphere of copper of radius $r = 0.01$ m, given that copper has density $\rho_c = 2700$ kg m^{-3} and specific heat capacity $c =$ 900 J kg^{-1} K^{-1}. If the total heat flux density to the sphere is $Q = 100$ W m^{-2}, calculate the rate of change of the temperature of the sphere.

   Answer:

   $C = \frac{4}{3}\pi r^3 \; \rho_c \, c = \;$ 10.18 J K^{-1}.

   $\frac{dT}{dt} = \frac{Q \, 4\pi r^2}{C} = \;$ 1.23 x 10^{-2} K s^{-1}

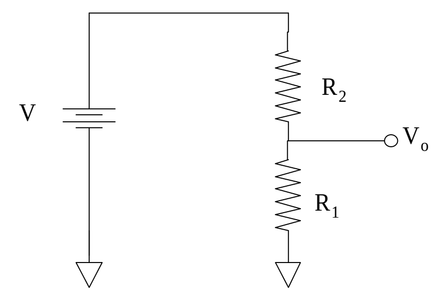
Data:

- $C \, \frac{dT}{dt} = A \; (\; Q^* + Q_H + Q_E \;) + \; P$

  Energy balance for a thermometer having bulk heat capacity C and surface area A The Q's are (left-to-right) the net radiative, sensible, and latent heat flux densities (W m^{-2}), and P is (any) internal heating.

- $V_o = V \; \frac{R_1}{R_1 + R_2}$

  Output of voltage divider


V
R2
Vo
R1