1.

a) Total resistance Rtot1 = R10 + (R20*R30)/(R20+R30) = 22 Ω. (1*p,* no need to provide value) Ammeter reading I = U / Rtot1 = 0.45 A (or 0.5 A). (1*p*)

b) Total resistance Rtot2 = R10 + (R20*Rtot1)/(R20 + Rtot1) = 20.5 Ω. (1*p*, no need to provide value) Ammeter reading I = U/Rtot2 = 0.49 A (or 0.5 A). (1*p*)

c) Total resistance: start from the right and see that R20 and R20 in parallel give R10 that is in series with the previous R10, giving R20 in total and you end up with the exact same circuit with *N* – 1 elements. You can do this until the first element, irrespective of the number of elements. Hence total resistance Rtot3 = 20 Ω. (1*p*, no need to provide value). Ammeter reading I = U/Rtot3 = 0.5 A. (1*p*)

2.

a) $V_{out} = E\, x\, R / (x\, R + (1 - x)\, R) = x\, E$. (*1p*)

b) $\tan\theta = d/L$, $\theta = (\pi/2)\, R_\theta / R_p$, Vout = $(R_\theta / R_p)\, E$, $d = L \tan((\pi/2)(V_{out} / E))$. (*1p*)

c) Number of wire turns in the potentiometer: 1500 (pi/2) (500 turns per cm, *r* = 3 cm), approximately 2356 turns. Distance expressed as a function of the turn *N* of the potentiometer is $d = L \tan((\pi/2)(N / 2356))$.

Accuracy is at its worst when the slide changes from one turn to another: $(d_{N+1} - d_N)/2$. Depends strongly on the distance! One should get an expression resembling the last one (with the possibility of plugging in numbers) in order to get the point. *(1p)*

Resolution: the slide can move from the middle of the turns N-1 and N to the middle of the turns N and N+1 without the reading changing. Hence the resolution is: $(d_N - d_{N-1})/2 + (d_{N+1} - d_N)/2$, approximately $d_{N+1} - d_N$. Any of these is OK. (*1p*)

Sensitivity: $V_{out} = (2\, E / \pi) \arctan(d/L)$, hence the sensitivity is $(2\, E / \pi)(1 + (d/L)^2)^{-1}$ *(1p)*

d) The relation for accuracy that one gets in (c) is a bit tricky to treat without a computer. It is easier to think about the distance as a function of N, and define accuracy as $d'(N)\, \Delta N / 2$, where $\Delta N = 1$. The derivative d'(N) tells how much d changes with one wire turn. Now we get $d'(N) = L\, (\pi/2)\, (1/2356)\, (\cos^2((\pi/2)(N/2356)))^{-1}$. Requiring that the accuracy is 10 m (and observing that d'(N) is a monotonously increasing function), we get the limit is N = 2344, corresponding to 250 m. (*1p*)

3.

a) T_1 = 12°C, T_2 = 100°C, T_f = 44°C , m_1 = 0.4 kg, m_2 = 0.4 kg, c_v = 4.184 kJ / (kg · K), calorimeter water equivalent W (in kg). $c_v m_2 (T_2 – T_f) = c_v (m_1 + W) (T_f – T_1)$ (the general formula: *1p*) gives $W = m_2 (T_2 – T_f) / (T_f – T_1) – m_1$ = 0.3 kg. *(1p)*

Now the copper pellets (heat capacity C_p, mass m_{Cu}).

T_1 = 14°C, T_2 = 100°C, T_f = 15°C , m_1 = 0.8 kg, W = 0.3 kg. $C_p (T_2 – T_f) = c_v (m_1 + W) (T_f – T_1)$

gives $C_p= c_v (m_1 + W) (T_f – T_1) / (T_2 – T_f)$ = 0.04 kJ/K. *(1p) (0.039 kJ/K OK)*

b) $c_{Cu} = C_p / m_{Cu}$ = 0.039 kJ/K / 0.083 kg = 0.474 kJ / (kg · K) > 0.385 kJ / (kg · K), significantly larger than the tabulated value. *(1p, it's ok to use 78 g or some average for the mass).* Main problem: inaccurate temperature measurement. If T_1 is in reality for example T_1 = 14.2°C, we get c_{Cu} = 0.380 kJ / (kg · K), which is already within the error produced by the determination of mass. Another (but less likely) option is that you are slow with taking the pellets from the boiling water and they cool down to to 80 – 85°C before being thrown into the calorimeter. Main general point: discussion of potential error sources in both the conduction of the experiment and in the measurements. Important also that the calorimeter is said to be thermally well insulated, hence it is not the source of problems.

c) Simple answer is OK: the formula changes as you need to include the heat of transformation as well. (*1p*)

4.

The experiment cannot be based on measuring time (*1p*).

You need to be able to split the beam of light (you need to measure a distance between light spots), piece of glass at a 45 degree angle the beam of light is a good start (*1p*)

Putting a mirror on the power drill is another good start (*1p*)

You have a realistic way of making the light travel 2 x 29 m = 58 m – this takes about 190 ns (*1p* for this or similar reasoning). The 30000 rpm drill will turn 0.034 degrees (or 0.0006 rad) in that time (*1p*). So, if you shoot a beam of light at the rotating mirror that then reflects from a mirror on the wall at the other end of the hall and comes back to the rotating mirror (given that you have aligned things well enough (also doable), at a distance of for example 2 m from the drill, will have moved 1.2 mm. Realistic. (*1p*)

People can of course be creative, the point being that 3p are given for the demonstrating an understanding of the basic experimental possibilities and constratings and another 3p for demonstrating by performing calculations that the plan is feasible.