31st International Physics Olympiad

Leicester, U.K.

Experimental Competition

Wednesday, July 12th, 2000

Please read this first:

1. The time available is 2 ½ hours for each of the 2 experimental questions. Answers for your first question will be collected after 2 ½ hours.
2. Use only the pen issued in your back pack.
3. Use only the front side of the sheets of paper provided. Do not use the side marked with a cross.
4. Each question should be answered on separate sheets of paper.
5. For each question, in addition to the ***blank writing sheets*** where you may write, there is an **a*nswer sheet*** where you *must* summarise the results you have obtained. Numerical results should be written with as many digits as are appropriate to the given data. Do not forget to state the units. Try, wherever possible, to estimate the experimental uncertainties.
6. Write on the blank sheets of paper the results of all your measurements and whatever else you consider is required for the solution of the question and that you wish to be marked. However you should use mainly equations, numbers, symbols, graphs and diagrams. Please use *as little text as possible*.
7. *It is absolutely essential* that you enter in the boxes at the top of each sheet of paper used your ***Country*** and your student number (***Student No***.). In addition, on the blank sheets of paper used for each question, you should enter the number of the question ***(Question No.)***, the progressive number of each sheet ***(Page No.)*** and the total number of blank sheets that you have used and wish to be marked for each question ***(Total No. of pages)***. It is also helpful to write the question number and the section label of the part you are answering at the beginning of each sheet of writing paper. If you use some blank sheets of paper for notes that you do not wish to be marked, put a large cross through the whole sheet and do not include it in your numbering.
8. When you have finished, arrange all sheets *in proper order* (for *each* question put answer sheets first, then used sheets in order, followed by the sheets you do not wish to be marked. Put unused sheets and the printed question at the bottom). Place the papers for each question inside the envelope labelled with the appropriate question number, and leave everything on your desk. You are not allowed to take *any* sheets of paper out of the room.

IPHO2000 EXPERIMENTAL QUESTION 1

CDROM SPECTROMETER

The aim is to produce a graph showing how the conductance* of a light-dependent resistor (LDR) varies with wavelength across the visible spectrum.

*conductance G = 1/resistance (units: mho, 1 mho = $1\Omega^{-1}$)

There are five parts to this experiment:

- *Using a concave reflection grating (made from a strip of CDROM) to produce a focused first order spectrum of the light from bulb A (12 V 50W tungsten filament).*
- *Measuring and plotting the conductance of the LDR against wavelength as it is scanned through this first order spectrum.*
- *Showing that the filament in bulb A behaves approximately as an ideal black body.*
- *Finding the temperature of the filament in bulb A when it is connected to the 12 V supply.*
- *Correcting the graph of conductance against wavelength to take account of the energy distribution within the spectrum of light emitted by bulb A.*

Precautions

- *Beware of hot surfaces.*
- ***Bulb B should not be connected to any potential difference greater than 2.0 V.***
- *Do not use the multimeter on its resistance settings in any live circuit.*

Procedure

(a) The apparatus shown in Figure 1 has been set up so that light from bulb A falls normally on the curved grating and the LDR has been positioned in the focused **first order** spectrum. Move the LDR through this **first-order** spectrum and observe how its resistance (*measured by multimeter X*) changes with position.

(b) (i) Measure and record the resistance R of the LDR at different positions within this first-order spectrum. Record your data in the blank table provided.

(ii) Plot a graph of the conductance G of the LDR against wavelength λ using the graph paper provided.

Note The angle θ between the direction of light of wavelength λ in the first-order spectrum and that of the white light reflected from the grating (see Figure 1) is given by:

$\sin\theta = \lambda/d$ where d is the separation of lines in the grating.

The graph plotted in (b)(ii) does not represent the sensitivity of the LDR to different wavelengths correctly as the emission characteristics of bulb A have not been taken into account. These characteristics are investigated in parts (c) and (d) leading to a corrected curve plotted in part (e).

- ***Note for part (c) that three multimeters are connected as ammeters. These should NOT be adjusted or moved. Use the fourth multimeter (labelled* X*) for all voltage measurements.***

(c) If the filament of a 50 W bulb acts as a black-body radiator it can be shown that the potential difference V across it should be related to the current I through it by the expression:

$$V^3 = CI^5 \qquad \text{where } C \text{ is a constant.}$$

Measure corresponding values of V and I for bulb A (in the can). *The ammeter is already connected and should not be adjusted.*

(i) Record your data and any calculated values in the table provided on the answer sheet.

(ii) Plot a suitable graph to show that the filament acts as a black-body radiator on the graph paper provided.

(d) To correct the graph in (b)(ii) we need to know the working temperature of the tungsten filament in bulb A. This can be found from the variation of filament resistance with temperature.

- **You are provided with a graph of tungsten resistivity (μΩcm) against temperature (K).**

If the resistance of the filament in bulb A can be found at a known temperature then its temperature when run from the 12 V supply can be found from its resistance at that operating potential difference. Unfortunately its resistance at room temperature is too small to be measured accurately with this apparatus. However, you are provided with a second smaller bulb, C, which has a larger, *measurable* resistance at room temperature. Bulb C can be used as an intermediary by following the procedure described below. You are also provided with a second 12V 50W bulb (B) identical to bulb A. Bulbs B and C are mounted on the board provided and connected as shown in Figure 2.

(i) Measure the resistance of bulb C when it is unlit at room temperature (*use multimeter X*, and take room temperature to be 300 K). Record this resistance R_{C1} on the answer sheet.

(ii) Use the circuit shown in Figure 2 to compare the filaments of bulbs B and C. Use the variable resistor to vary the current through bulb C until you can see that overlapping filaments are at the same temperature. If the small filament is cooler than the larger one it appears as a thin black loop. Measure the resistances of bulbs B and C when this condition has been reached and record their values, R_{C2} and R_B, on the answer sheet. *Remember, the ammeters are already connected.*

(iii) Use the graph of resistivity against temperature (supplied) to work out the temperature of the filaments of B and C when they are matched. Record this temperature, T_{2V}, on the answer sheet.

(iv) Measure the resistance of the filament in bulb A (in the can) when it is connected to the 12 V a.c. supply. *Once again the ammeter is already connected and should not be adjusted*. Record this value, R_{12V} on the answer sheet.

(v) Use the values for the resistance of bulb A at 2 V and 12 V and its temperature at 2 V to work out its temperature when run from the 12 V supply. Record this temperature, T_{12V} in the table on the answer sheet.

- **You are provided with graphs that give the relative intensity of radiation from a black-body radiator (Planck curves) at 2000 K, 2250 K, 2500 K, 2750 K, 3000 K and 3250 K.**

(e) Use these graphs and the result from (d)(v) to plot a corrected graph of LDR conductance (arbitrary units) versus wavelength using the graph paper provided. Assume that the conductance of the LDR at any wavelength is directly proportional to the intensity of radiation at that wavelength (This assumption is reasonable at the low intensities falling on the LDR in this experiment). Assume also that the grating diffracts light equally to all parts of the first order spectrum.

MARK SHEET FOR QUESTION 4 (maximum 10 marks)

Detailed interpretation:

(b)(i) TOTAL MARK: 1.0 MARKS

range of visible wavelengths: **0.3 marks**

this tests their ability to take readings and calculate wavelengths from the diffraction grating formula

at least 7 values spread across range: **0.3 marks**
(5, 6 values 0.2 marks)
(4 values 0.1 marks)
(less than 4 0 marks)

complete set of values for conductance: **0.1 marks**
agreement with measured value (10%) **0.2 marks**
(within 20% 0.1 marks)

clear tabulation of resistance and conductance values: **0.1 marks**

(b)(ii) TOTAL MARK: 2.0 MARKS

graph of conductance against wavelength:

if it does show a peak: **0.2 marks**
if peak is 580 nm ± 20 nm **0.3 marks**
(550 nm - 560 nm or 600 nm - 610 nm 0.1 marks)
(outside this range 0.0 marks)

labels on axes **0.2 marks**
units indicated **0.2 marks**
correct plotting of data points **0.2 marks**
appropriate scale **0.2 marks**
good line **0.2 marks**

evidence of investigation of peak: **0.5 marks**

(c) TOTAL MARK: 2.0 MARKS

(i) table giving full range of V and I values

At least 4 values: **0.2 marks**
(3 values 0.1 marks)
(<3 values 0.0 marks)

Clear tabulation including units and labels **0.3 marks**
correct measurement of voltage: **0.2 marks**
calculated values (V^3 and I^5) or logs: **0.2 marks**

(c)(ii) graph showing V^3 proportional to I^5:

straight line		**0.3 marks**
through/close to origin (power graph)		**0.3 marks**
OR gradient (of log graph) about 1.7	**OR**	**0.3 marks**
labels on axes		**0.1 marks**
units indicated		**0.1 marks**
correct plotting		**0.2 marks**
appropriate scale		**0.1 marks**

(d) MAXIMUM MARK: 3.0

(d)(i) resistance of bulb C unlit at 300 K (13.5 Ω±1Ω) **0.2 marks**

(d)(ii) resistance of bulb C when matched to B (90 Ω ± 5 Ω) **0.2 marks**
resistance of bulb B when matched to C (1.2 Ω ± 0.2 Ω) **0.2 marks**

(d)(iii) temperature of filaments in C and B when matched: **0.8 marks**
(consistent with values in (i) and (ii))

(d)(iv) resistance of bulb A when connected to 12 V a.c. (2.85 Ω ± 0.15 Ω) **0.4 marks**

(d)(v) temperature of filament in A when connected to 12 V a.c.
consistent with previous values **1.0 marks**
2900 K ± 20% **0.2 marks**

(e) **corrected graph: MAX MARK: 2.0 MARKS**

use of appropriate Planck curve:	**0.2 marks**
consistent correction factor using *G* proportional to *I*:	**0.6 marks**
clear tabulation	**0.2 marks**
corrected graph of G against I:	**0.6 marks**
graph must be consistent with original data	
labels on axes	**0.1 marks**
units indicated	**0.1 marks**
correct plotting	**0.1 marks**
appropriate scale	**0.1 marks**

Figure 1 - Experimental arrangement for (a)

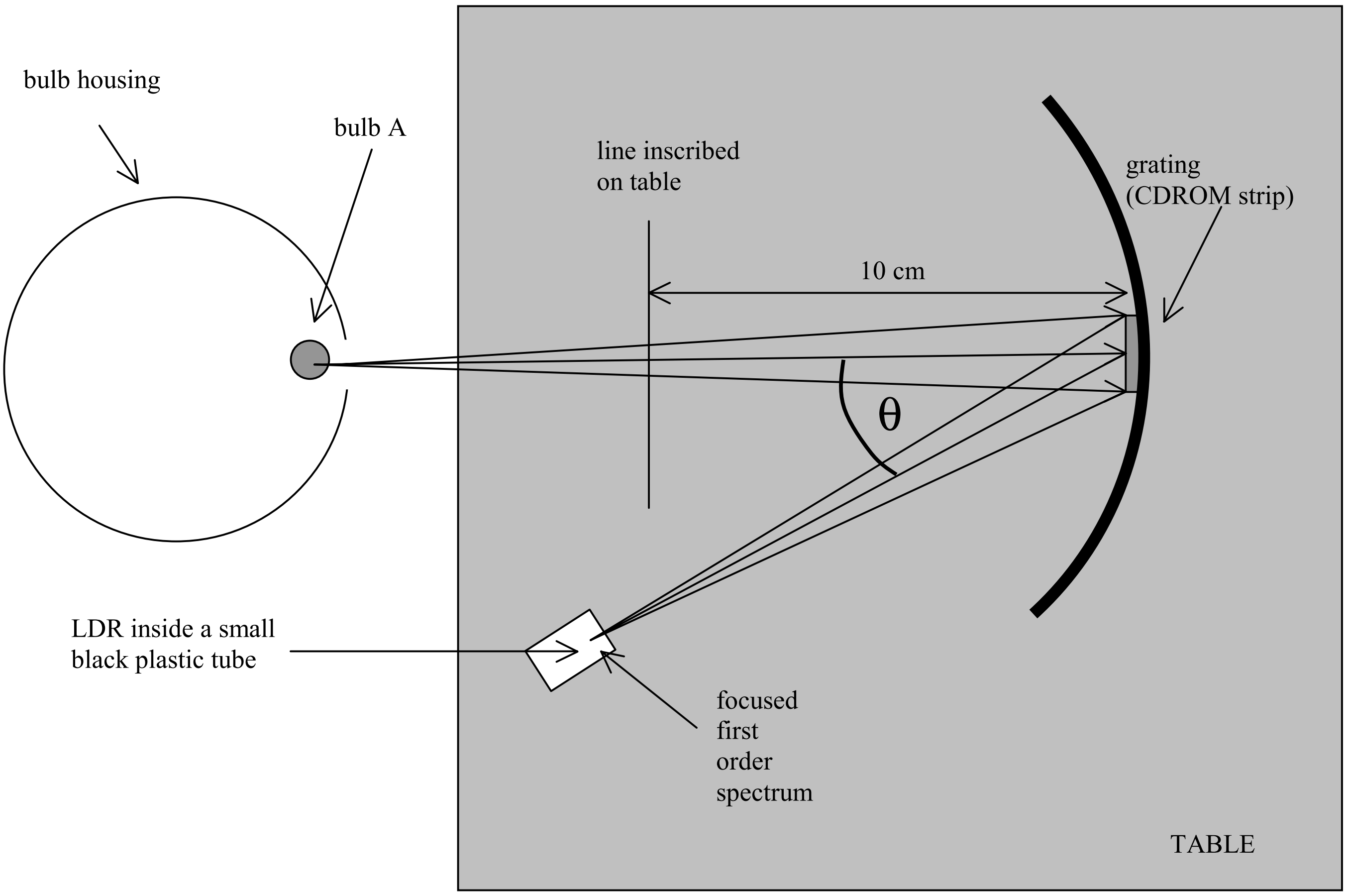


Figure 1: Detail - the grating:

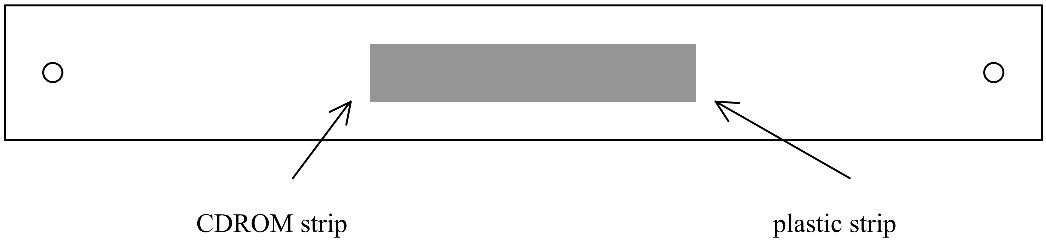


Figure 1: Detail - LDR and Multimeter:

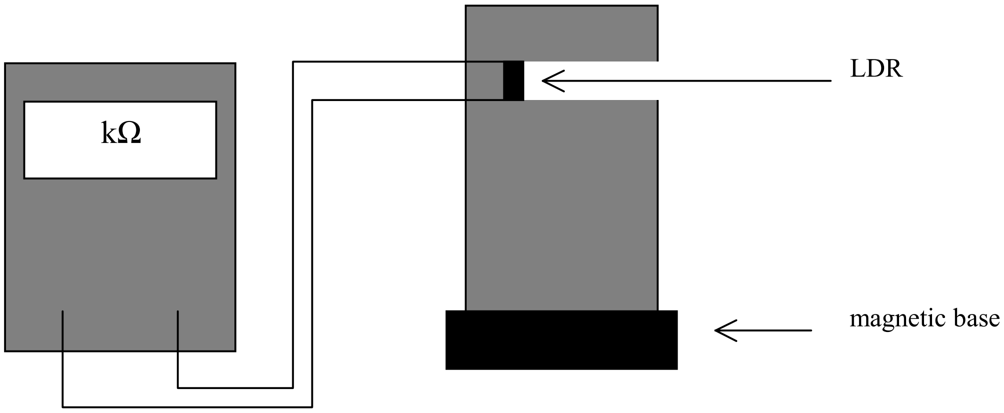
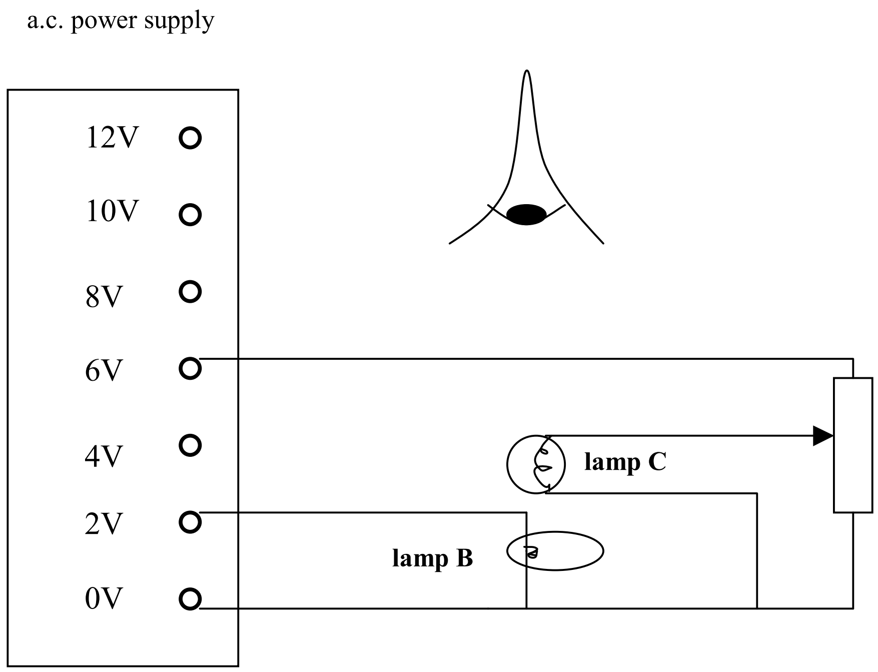
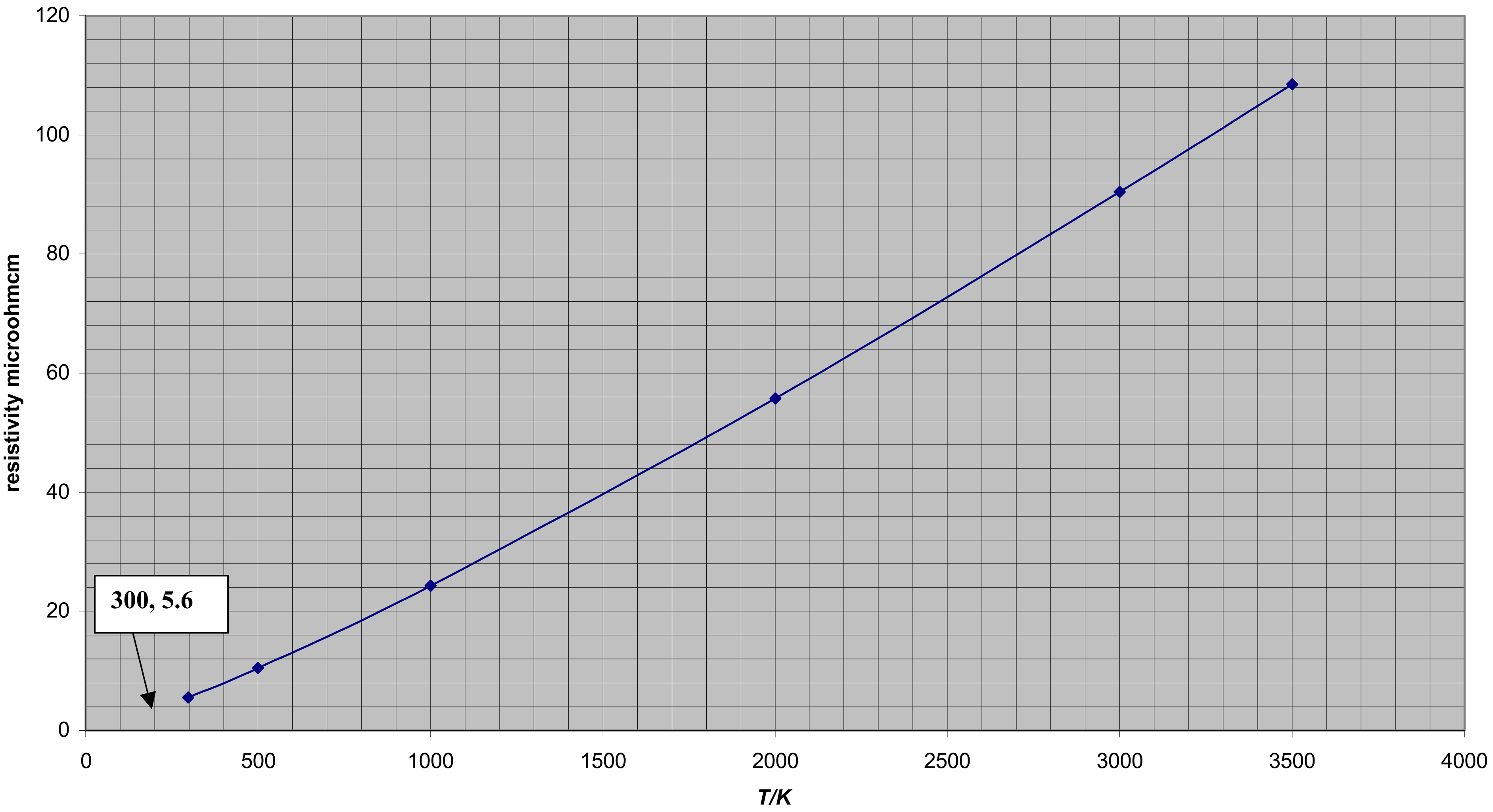


Figure 2

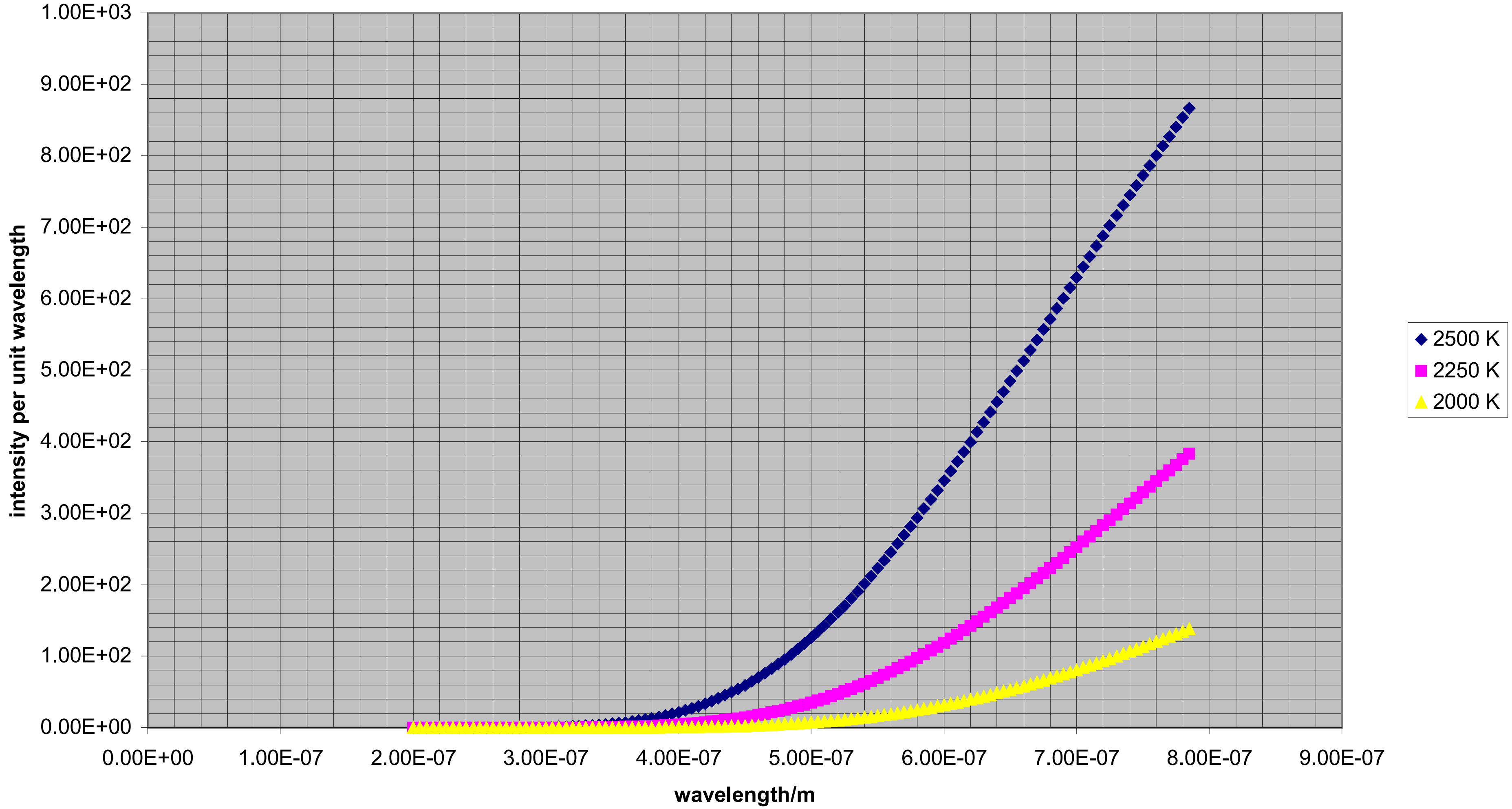
Note that this diagram does not show meters



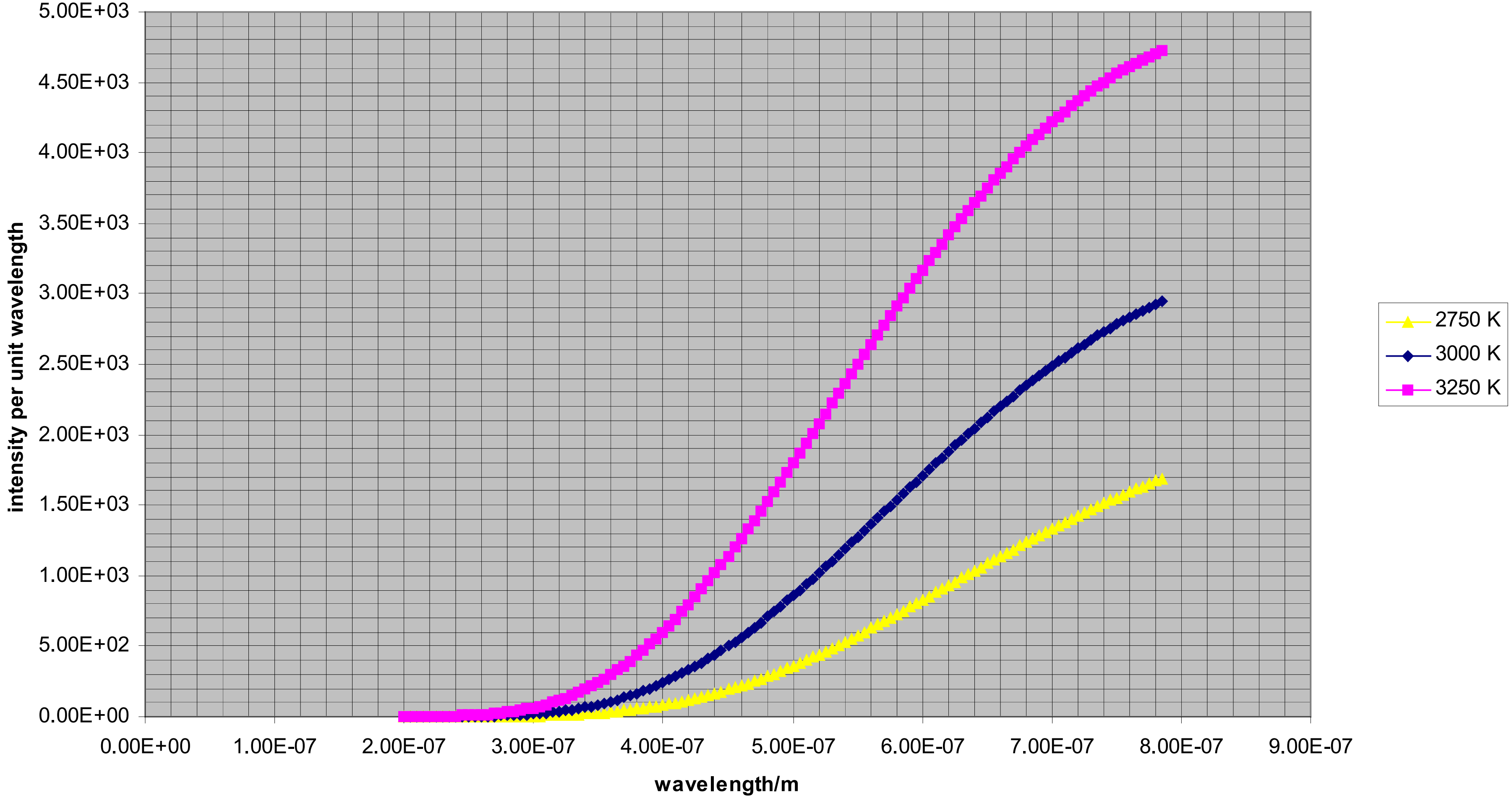
Graph 1: tungsten resistivity



Graph 2(a): Planck Curves for 2000 K, 2250 K, 2500 K



Graph 2(b): Planck Curves for 2750 K, 3000 K, 3250 K



The Magnetic Puck

July 2000

2.5 hours

In this experiment you ARE expected to indicate uncertainties in your measurements, results and graphs.

Aim

To investigate the forces on a puck when it slides down the slope.

Warning

*Do **not touch** the circular flat faces of the puck or the paper surface of the slope with your hands. Use the glove provided. The faces have different coloured paper stickers for convenience but the frictional characteristics of the paper faces may be assumed to be the same.*

Timing

The sensors underneath the track trigger electronic gates in the box and the green LED will light when the puck is between the sensors. The multimeter measures the pd across a capacitor, which is connected to a constant current generator whilst the green light is on. The reading of the multimeter is therefore a measure of the time during which the puck is between the sensors. This reading can give a value for the speed of the puck in arbitrary units.

Operating the timer

i) Press and hold down the black push button on the side of the box. This switches the electronics on.

ii) If the green light goes on slide the puck (light face up) past the lower sensor. The green light should go off.

iii) The pd across the capacitor can be reduced to zero before the puck is released by pressing the red button for at least 10s.

iv) The battery pd can be measured by connecting the multimeter across the terminals marked with the cell symbol.

Definitions

(i) A moving body sliding down an inclined plane experiences a tangential retarding force *F* and a normal reaction *N*. Define

$$\xi = \frac{F}{N}$$

(ii) When the retarding force is due to friction alone, ξ equals μ and is called the dynamic coefficient of friction for the surface. It is independent of speed.

(iii) When the blue (dark) side is in contact with the plane define

$$\xi_d = \frac{F_d}{N}$$

where the tangential force F_d is partly due to the surface friction and partly due to magnetic effects.

The variable ξ_{ds} which gives the magnetic effects only is defined by

$$\xi_{ds} = \xi_d - \mu$$

Data

Weight of puck = 5.84×10^{-2} N
pd/timing relation at battery pd of 9.0 V: 1V = 0.213 s
Distance between sensors = 0.294 m

Important hints and advice

(i) You will find it helpful initially to investigate the behaviour of the puck qualitatively.
(ii) Think about the physics before you do a quantitative investigation. Remember to use graphical presentation where possible.
(iii) Do not attempt to take too many experimental readings unless you have plenty of time.
(iv) You are measuring the pd across an electrolytic capacitor. This does not behave quite like a simple air capacitor. Slow leakage of charge is normal and the pd will not remain completely steady.
(v) You are given one puck and one 9.0 V battery. Conserve the battery! The constant current filling the capacitor is proportional to the battery pd. It is therefore advisable to monitor the battery pd . In addition the sensors may not be reliable if the pd of the battery falls below 8.4 V.
(vi) Your answer pack only contains 4 sides of graph paper. You will not be given further sheets. You may keep the puck at the end of your experiment.
(vii) If you have trouble operating the multimeters ask an invigilator.

Experiment

Using only the apparatus provided investigate how ξ_{ds} depends on the speed v_θ of the puck for track inclinations θ to the horizontal.

State on the answer sheet the algebraic equations/relations used in analysing your results and in plotting your graphs.

Suggest a quantitative model to explain your results. Use the data which you collect to justify your model.

IPhO 2000

Country	Student No	Question No	Page No	Total No of pages

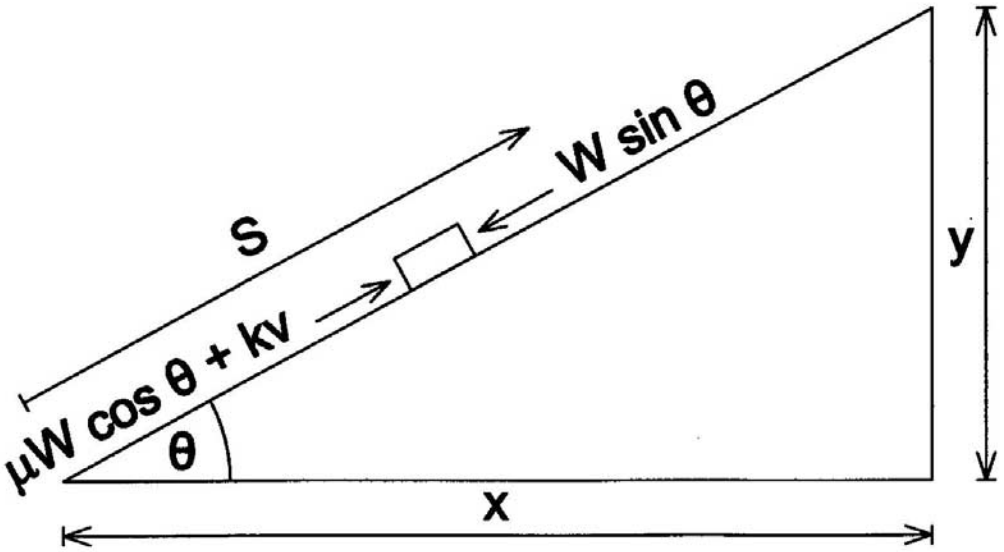
Answer Sheet

μ =

Relation between ξ_{ds} *and* v *and* θ

MAGIC PUCK EXPERIMENT

General theory for puck sliding down the slope at constant speed *v*



(s = distance up slope from mid-point between sensors)

Preliminary thinking should indicate that the magnetic retarding force $F = kv$*.
This retarding force can also be expressed as $\xi_{ds}\, W \cos\theta$

where W is the weight of the puck
ξ_{ds} is the "magnetic" coefficient of friction alone
θ is the inclination of the slope to the horizontal

Therefore considering the forces operating parallel to the slope at a constant puck speed v:

weight component down = magnetic resistive force + frictional resistive force

$$W \sin\theta = kv + \mu W \cos\theta$$

Should we want to determine k and μ, this equation can be rendered into linear form by dividing through by $W \cos\theta$:

$$\tan\theta = kv/W\cos\theta + \mu$$

This gives the opportunity of plotting data, $\tan\theta$ against $v/\cos\theta$

The gradient of this graph will be k/W, the intercept will be μ.

But k/W, the gradient, is the same as $\xi_{ds}(\cos\theta)/v$.

Conclusion, relating ξ_{ds}, v and θ is: ξ_{ds} = gradient ($v/\cos\theta$)

NOTE: Raw readings will be of V, which can be converted to t using $t = 0.213$ V and thence to v using $v = 0.294/t$. So $v = 1.380/V$.

*Some competitors might choose (e.g.) $F = kv^2$. If so, modify expressions accordingly.

Alternative theory using work/energy considerations

From energy considerations:

potential energy lost = kinetic energy gained + work done against friction

We can say that, for the puck dropping distance y over a considerable accelerating distance s and starting at zero speed

$$Wy = (1/2)mv^2 + [(\xi_{ds} + \mu)\, W \cos\theta] \times s$$

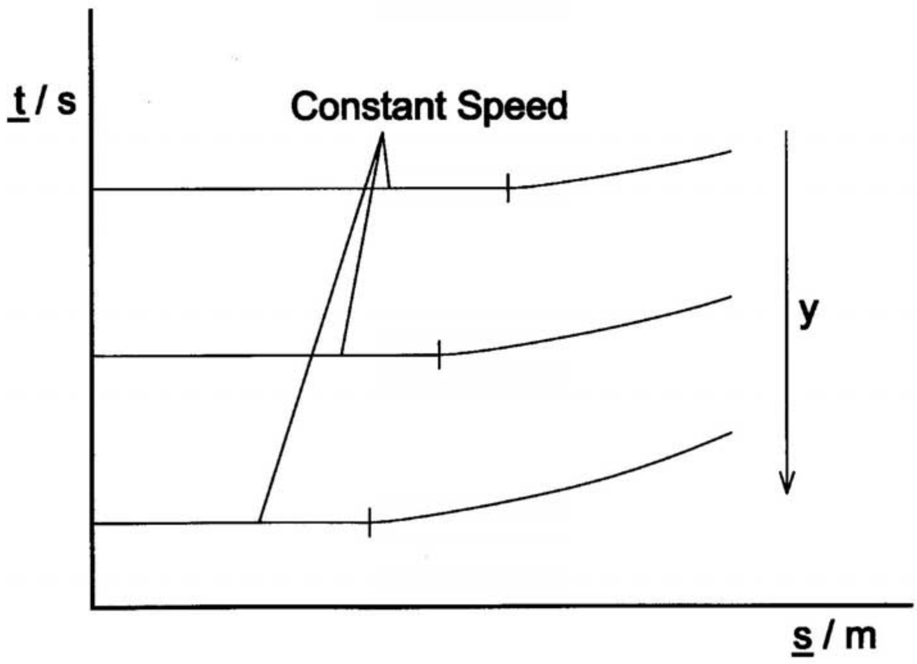
Note that ξ_{ds} varies with v, so that in this expression ξ_{ds} represents a "mean" value of a speed-dependent function. Also there will be uncertainty about overcoming static friction at the starting point: urging the puck to start will create a non-zero starting speed. However in practice it is found that the puck will attain a terminal speed, albeit briefly, so the foregoing theory for constant speed relations can be applied again <u>provided suitable track inclinations can be found to give a measurable constant speed.</u>

So this approach to the problem will give the competitors greater difficulties, possibly without a result being reached.

Detecting a constant speed condition

The puck can be released from various points on the inclined track. If two or more adjacent timings give identical results then the corresponding release points will cause the puck to pass between the sensors at a constant speed.

Quite extensive graphical analysis might be required to establish this condition for different slope inclinations θ. Straight horizontal lines on a t (vertical) against s (distance from sensors) graph indicate the desired condition.



Marking scheme

Penalties	- 0.01 for each minor shortcoming or omission - 0.5 for each major deficiency		

A Competitors have been warned to monitor the battery p.d.
correction made to **ALL** voltage readings through experiments 2 [2]
(If corrections made to more than a half of the readings, award a single mark.)

B hypothesis advanced that magnetic resistive force $F = kv$ (or e.g. kv^2) 1
algebraic justification for this (e.g. $E = d\varphi/dt$, $I = E/R$, $F = BIL$) 2 [3]

C determination of an accurate value of the non-magnetic component μ of the coefficient of friction (see answer sheet and also E7).

Method 1: Find θ at which the puck will descend at a very slow constant speed and then apply $\mu = \tan\theta$. Note that the puck will need a slight urge to start it moving: otherwise (with no urge) the static coefficient will be obtained; with a higher speed magnetic effects will intervene. The constant speed condition can be confirmed by starting the puck at different points in the track: constant voltage readings will indicate the correct θ. The result for μ will probably be in the range 0.2 to 0.4.

idea that $\mu = \tan\theta_{min}$			1	
$V - s$ readings for various θ (or y)	n x 1 to	maximum	4	
readings for determining $\tan\theta$ (e.g. via y/x)			1 + 1	
error range for $\tan\theta$, hence of μ			1	
result close to acceptable range (0.2 – 0.4)			1	
expressed with appropriate precision (2 or 3 decimal places)			1	[10]

Method 2

V (or t) – v readings recorded for various θ	n x 1 to	maximum	4	
plot values of v (vertically) against $\tan\theta$ (horizontally) for one side of the puck			2	
read off horizontal intercept	(= μ)		1	
(Bonus mark: repeat all stages for other side			2)	
error range for μ			1	
result in acceptable range			1	
expressed with appropriate precision (s.f.)			1	[10]

D **Detecting a constant speed condition**

readings of s for at least three values of θ	n x 1	3	
2 values of s used in each set		1	
3 values of s used in each set		1	
representation of results in graphical form	($t - s$ OR $v - s$)	4	
constant speed condition established and indicated clearly		1	[10]

E Investigation of $\xi_{ds} – v - \theta$ (“dark side of puck”: constant speed theory)

1. statement of suitable/correct mathematical model to be investigated

e.g. $\zeta_d = (k/W)(v/\cos\theta) + \mu$

(must be a single expression) 5

2. statement of functions to plot to verify THEIR model
e.g. tan θ and v/cos θ 2

3. collection of data for these functions (each set 2 marks) 10

4. plot graph to support this model (each correct point 2 marks) 10

5. plot produces a straight line 2

6. graph parameters interpreted to give numerical values for model 5

7. μ value determined from graph with a value within 20% of result in C 1* [35]

*Some competitors might treat this as their sole determination of μ. If so marks for C can be awarded here.

recognition of graph feature (intercept) representing μ	2	
result in acceptable range	2	
expressed with appropriate precision	1	[5]

Mark summary

A	**/2**	**B**	**/3**	**C**	**/10**	**D**	**/10**	**E**	**/35**

Divide by 6 to find mark on uniform scale to 1 d.p. Round to nearest single decimal place.

Uniform scale mark **/10**