

BPhO

British Physics Olympiad

BPhO Physics Challenge September/October 2022

Instructions

Time: 1 hour.

Questions: Answer ALL questions.

Marks: Total of **50 marks**.

Instructions: You are allowed any standard exam board data/formula sheet.

Equipment: Any standard non-graphical calculator may be used.
Ruler and pencil may be needed.

Solutions: These questions are about problem solving. Draw diagrams in order to understand the questions. You must write down the questions in terms of symbols and equations; then try calculating quantities in order to work quickly towards a solution. In these questions you will need to explain your reasoning by showing clear working. Even if you cannot complete the question, show how you have started your thinking, with ideas and, generally, by drawing a diagram.

Clarity: Solutions must be written legibly and set out properly with a “narrative” which links one step to the next (and, so, therefore, hence, but, also, using equ 5, etc.).

Important Constants

Constant	Symbol	Value
Speed of light in free space	c	$3.00 \times 10^8 \text{ m s}^{-1}$
Elementary charge	e	$1.60 \times 10^{-19} \text{ C}$
Mass of electron	m_e	$9.11 \times 10^{-31} \text{ kg}$
Atomic mass unit	u	$1.66 \times 10^{-27} \text{ kg}$
Earth's gravitational field strength	g	9.81 N kg^{-1}
Atmospheric pressure at the Earth's surface	P_0	$1.01 \times 10^5 \text{ Pa}$
Planck constant	h	$6.63 \times 10^{-34} \text{ J s}$
Avogadro constant	N_A	$6.02 \times 10^{23} \text{ mol}^{-1}$

Qu 1. This question is about estimations.

Especially at the start of research or when solving a complex problem, it is useful to have an estimate of the sort of outcome to expect; making approximate calculations is a useful skill. Use the suggestions given and any other estimated values of your own to answer the following:

- a) (i) An experimental vessel having a glass viewing window $10\text{ cm} \times 10\text{ cm}$ is evacuated by a moderately efficient vacuum pump. What is the approximate force on the window caused by the pressure difference across it?
- (ii) Comment on a young experimenter's assertion that disastrous results might occur from using a better quality pump, which would make the residual pressure 1000 times smaller.

[3]

- b) What is the approximate radius of a balloon (hydrogen or helium) which could lift a single person? You may ignore the weight of the balloon itself.

[3]

- c) It has been suggested that a tyre when gripping the road properly, i.e. without slipping, leaves behind a monolayer of rubber on the road surface. A new tyre has a tread depth of 8 mm and should be replaced when the remaining tread approaches the UK legal limit of 1.6 mm. Estimate the distance that a tyre is likely to travel during its useful life.

[3]

[9 marks]

Qu 2.

This question relates to ways in which light energy may be concentrated in an interference pattern.

Figure 1 shows wave fronts at normal incidence on a Young's double slit arrangement, illuminating them so that they both radiate in phase, each with an amplitude A at the screen. One such slit *alone* will cause an intensity of illumination of I , where $I \propto A^2$, in the central region of the screen where the Young's fringes pattern forms.

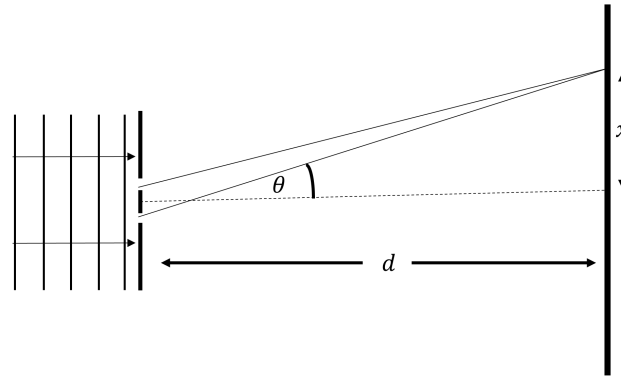


Figure 1: Young's double slits.

- a) (i) What is the resultant amplitude of the waves from the slits arriving at the screen at a maxima (a bright fringe), where the incoming waves arrive in phase? [1]
- (ii) Therefore, what is the intensity at the maxima? [1]

This result on, the face of it, seems paradoxical as we might carelessly think that we have gained energy from nowhere.

- (iii) What is the intensity at the minima, [1]
- (iv) and therefore what is the average intensity across the whole pattern? [1]
- (v) Comment on this result in terms of conservation of energy. [1]

Here we have considered the special case of two equal slits: we could now check whether the approach works for *unequal* slits.

- b) (i) Repeat parts (i) to (v) with slits delivering amplitudes A and $3A$. [3]
- (ii) Finally, show that this energy conservation calculation works for any general combination of slits giving amplitudes A_1 and A_2 at the screen. [2]

[9 marks]

Qu 3. This question explores a part of mechanics which can be developed from a very simple starting point.

For the first part of this question, assume that all the pulleys and cords are light and that the pulleys run smoothly.

- a) (i) **Figure 2** shows a load of mass, m , supported by a simple pulley system with a tension T in the cord. What is the value of the tension?
- (ii) What length of cord must be extracted at the free end, **X**, to raise the mass through a distance h ?

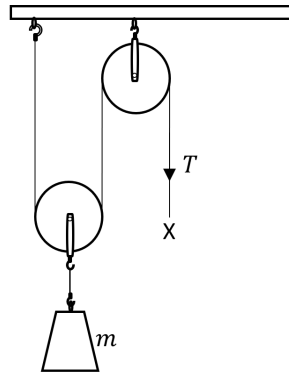


Figure 2: Two light pulleys and a light cord.

- (iii) Therefore how much work is done by the external agent pulling cord towards **X** ?
- (iv) State the increase in gravitational potential energy of the mass and comment on the mechanical efficiency of this arrangement.

[3]

Figure 3 shows a more complex system, known as a *block and tackle*, consisting of two light pulley blocks and a light cord.

b) Repeating the steps from part (a):

- (i) What is the value of the tension in the cord?
- (ii) What length of cord must be extracted at the free end, **X**, to raise the mass through a distance h ?
- (iii) Therefore, how much work is done by the external agent pulling cord towards **X** ?
- (iv) State the increase in gravitational potential energy of the mass, and comment on the mechanical efficiency of this arrangement.

[3]

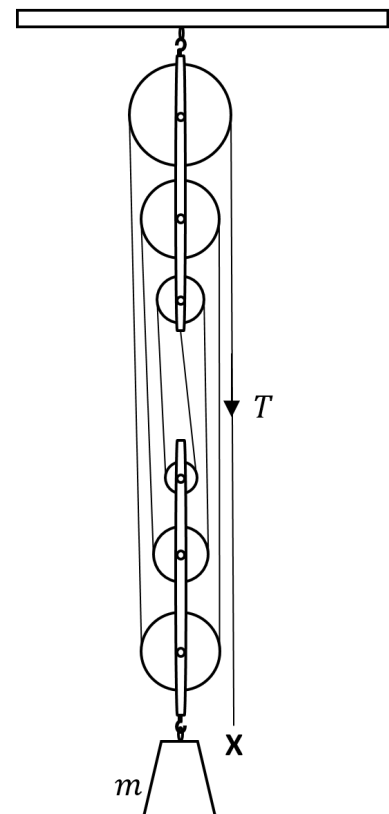


Figure 3: Two light pulley blocks and a light cord.

Clearly, any friction in the mechanism will lead to inefficiency: it is, however, instructive to examine the assumption that the pulley blocks have negligible mass.

Figure 4 shows a more realistic system, in which the lower half of the system (the pulley block) has a mass m/k , where k is a numerical parameter.

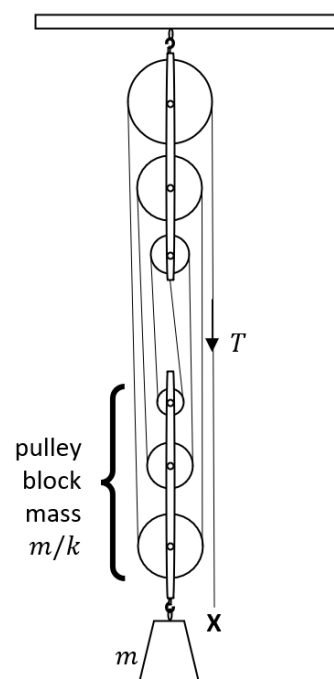


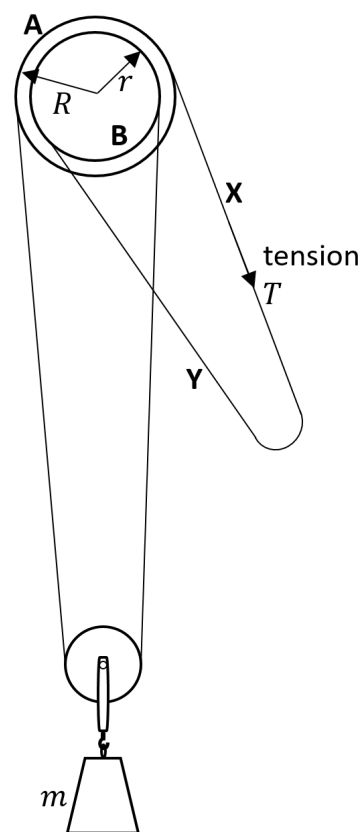
Figure 4: Two pulley blocks and a light cord.

- c) Repeating the steps from part (a):
- What is the value of the tension in the cord?
 - What length of cord must be extracted at the free end, **X**, to raise the mass through a distance h ?
 - Therefore, how much work is done by the external agent pulling cord towards **X**?
 - Use your result to find the efficiency of this more realistic system.

[3]

A novel variant, known as the *Weston Differential Pulley*, which is able to lift very heavy loads, is shown in **Figure 5**.

- d) The upper pulley consists of two parts, **A** and **B**, of radii R and r respectively, rigidly fixed together so that they rotate as one body. There is sufficient friction to ensure that the cord does not slip on the composite pulley. As you did in part (a), assume that the mass of the lower block is negligible and that the pulleys are free-running.



- What length of tight cord is extracted at **X** in one revolution of the upper pulley?
- What length of slack cord is drawn in at **Y** in one revolution of the upper pulley?
- Therefore, what is the change of height of the lower pulley and the load, m , during one revolution of the upper pulley?
- Hence, or otherwise, determine the tension at **X** required to lift the load of mass m .
- As the use of this system tends towards the lifting of very large loads what value of r , in terms of R , might be needed? Why is this not a practical proposition?

[6]

Figure 5: Weston Differential Pulley.

[15 marks]

Qu 4. This question explores issues around a commonplace domestic electrical device.

Modern sets of decorative lights, based on LED technology, are popular, efficient and safe. However, their forerunners had a poor reputation on safety grounds.

- a) **Figure 6** shows the principles of a set of ‘fairy lights’ used to decorate an indoor tree in, say, the 1960s. It consists of 20 identical 12 V incandescent light bulbs (now illegal on energy grounds!) connected in series.

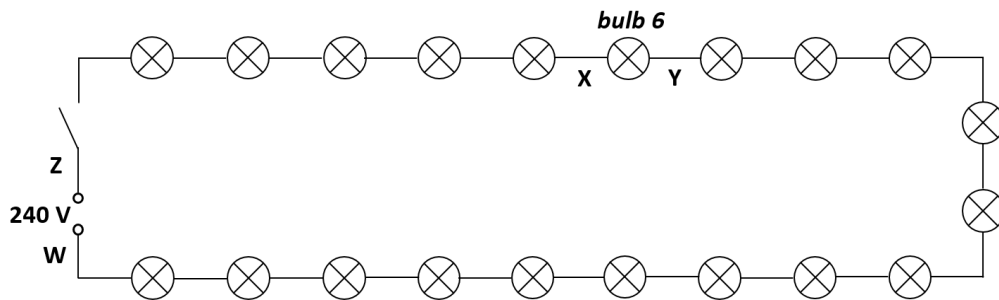


Figure 6: Decorative tree lights circuit of the 1960s.

- (i) Even when the lights are functioning correctly from an electrical point of view, the tree decorated in this way presents a serious risk to life. Suggest one reason why this may be.
- (ii) Show that the arrangement of bulbs will function correctly when connected to a 240 V supply.
- (iii) What is the p.d. between **W** and **X** when the system is functioning correctly?

[3]

- b) Difficulties arise if a bulb fails (i.e. the filament breaks, effectively giving the bulb infinite resistance).
- (i) Explain what will be seen when this occurs.

Clearly, a householder could substitute a new bulb for each one in turn until the faulty bulb has been discovered and replaced. This is very laborious so the householder decides to try use a voltmeter to discover the faulty bulb. (DO NOT actually do any such thing as the method adopted is a physics exercise to illustrate the *dangers* involved: probing electrical apparatus, especially when it is live, in this way can be FATAL)

In answering the following, let us assume *bulb 6* (between points **X** and **Y**) is faulty.

- (ii) As a precaution, the householder sets the switch to ‘off’. They then proceed to measure the potentials (with respect to **W**) of the terminals of each lamp. What p.d. will they measure between **W** and **X**? And between **W** and **Y**? Use your answers to explain why this method is ineffective.
- (iii) The householder therefore decides to set the switch to ‘on’. What p.d. will they now measure between **W** and **X**? And between **W** and **Y**? Is this the basis of an effective method for locating the fault?

- (iv) Believing they have found the fault, the householder removes **bulb 6** and in an effort to be careful, also checks the potential difference between **Z** and **X** with the switch still closed. What do they now measure?
 - (v) Removing **bulb 6** exposes the bulb contacts: explain what is likely to happen to the householder if they accidentally touch the contacts while replacing the bulb.
- [9]

c) More modern decorations based on filament bulbs are designed to avoid the problem from b(i) above. In doing so, they present an even more insidious danger. These later types use special bulbs which are not removable, thus eliminating the dangers already described. They work by automatically making an electrical short circuit to bypass the broken filament, so maintaining the continuity of the circuit.

- (i) Explain what will be seen when **bulb 6** fails
- (ii) What will be the potential differences across **bulb 6** and across any other bulb when this has happened?
- (iii) Comment on the brightness and the expected life of the remaining, un-failed bulbs.
- (iv) Explain why this situation could rapidly develop into serious fire risk.

[5]

[17 marks]

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