# PHYSICS

## 2013 National Qualifying Examination

***Time Allowed:***

***Reading Time: 10 minutes***

***Examination Time: 120 minutes***

### INSTRUCTIONS

- *Attempt ALL questions in both sections of this paper.*
- Permitted materials: a *non-programmable, non-graphical* calculator, blue and black pens, lead pencils, an eraser, and a ruler. **A lead pencil is essential. Ask for one if you do not have one.**
- Answer SECTION A on the MULTIPLE CHOICE ANSWER SHEET provided.
- Answer SECTION B in the answer booklet provided. Write in pen and use pencil only for diagrams, graphs and experimental work.
- You may attempt the questions in Section B in any order. Make sure that you label which parts are for which questions.
- **Do not write on this question paper. It will not be marked.**
- Do **not** staple the multiple choice answer sheet or the writing booklet to anything. They must be returned as they are.
- Ensure that your diagrams are clear and labelled.
- All numerical answers must have correct units.
- Marks will not be deducted for incorrect answers.

### MARKS

| | | |
|---|---|---|
| Section A | 10 multiple choice questions | 10 marks |
| Section B | 4 written answer questions | 55 marks |
| | | **65 marks** |

## SECTION A: MULTIPLE CHOICE
## USE THE ANSWER SHEET PROVIDED

Throughout, take the acceleration due to gravity to be $9.8\ \mathrm{m\,s^{-2}}$.

**Question 1**

When an incandescent light bulb has a current passing through its filament the filament heats and its resistance increases. If the light bulb is connected to a constant voltage source:

a. the resistance increases at a roughly constant rate and the current through the light bulb decreases correspondingly.

b. the resistance increases at a roughly constant rate and the current through the light bulb increases correspondingly.

c. the resistance increases but the current remains the same.

d. the resistance increases at a decreasing rate and the current increases at a decreasing rate until they are both roughly constant.

e. the resistance increases at a decreasing rate and the current decreases at a decreasing rate until they are both roughly constant.

**Question 2**

Which of the following is the best estimate of the speed of a parrot flying?

a. $3 \times 10^{-3}\ \mathrm{m\,s^{-1}}$

b. $1 \times 10^{-1}\ \mathrm{m\,s^{-1}}$

c. $3 \times 10^{0}\ \mathrm{m\,s^{-1}}$

d. $1 \times 10^{2}\ \mathrm{m\,s^{-1}}$

e. $3 \times 10^{3}\ \mathrm{m\,s^{-1}}$

**Question 3**

When a screw is very tight the most effective way to loosen it is by:

a. using a screwdriver with a fat handle and pushing down hard while turning to increase the grip.

b. using a screwdriver with a fat handle and not pushing down too hard in case you deform the screw head.

c. using a long screwdriver so that you are applying the force a long way from the point of contact.

d. using a short screwdriver with a thin handle so that you are applying the force as close as possible to the point of contact.

e. None of the above. A spanner is a more appropriate tool.

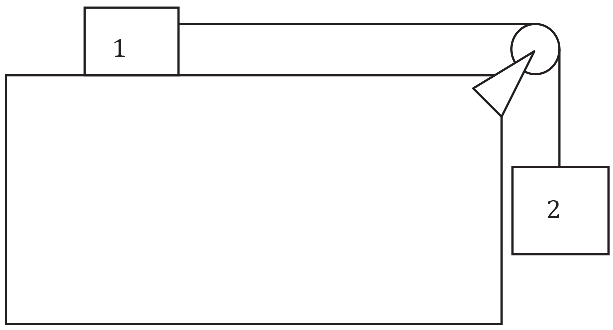
**Question 4**
Kate has a bucket of ice cream and wants to take it on a long car trip into the desert, so she wraps it in a jumper. Is this a good idea? Choose the best answer.

a. No. The jumper will make the ice cream hotter.
b. Yes. The jumper will hold the cold in the ice cream.
c. No. The jumper always moves the cold to outside it.
d. Yes. The jumper will prevent the heat getting to the ice cream.
e. No. The jumper won't make any difference to what happens to the ice cream.

**Question 5**
Which of the following is the best estimate of the mass of a 3D model aeroplane which is 20cm long and made of formed sheet aluminium?

a. 0.5 g
b. 5 g
c. 50 g
d. 500 g
e. 5 kg

**Question 6**
Two blocks are connected as shown. Block 1 has mass 5 kg and is on a frictionless, horizontal surface. Block 2 has mass 8 kg and is attached to block 1 by a rope with negligible mass, passing over a frictionless pulley. What is the acceleration of block 2?




a. $15.9\ \mathrm{m\,s^{-2}}$
b. $9.8\ \mathrm{m\,s^{-2}}$
c. $6.0\ \mathrm{m\,s^{-2}}$
d. $3.8\ \mathrm{m\,s^{-2}}$
e. $0\ \mathrm{m\,s^{-2}}$

**Question 7**

A shark, with a sucker-fish attached, is swimming at constant speed looking for prey. Under these conditions:

a. there is zero nett force on both the shark and the sucker-fish.

b. the nett force on the shark is greater than the nett force on the sucker-fish because the shark has a larger mass.

c. the swimming shark experiences a nett force but the sucker-fish does not because it is holding on.

d. the nett force on the shark is always the same as that on the sucker-fish because they always have the same speed.

e. the drag from the sucker-fish on the shark means that the nett force on the shark is less than on the sucker-fish.

**Question 8**

The shark, with a sucker-fish still attached, spots a possible meal and accelerates suddenly towards it. Under these conditions:

a. there is zero nett force on both the shark and the sucker-fish.

b. the nett force on the shark is greater than the nett force on the sucker-fish because the shark has a larger mass.

c. the swimming shark experiences a nett force but the sucker-fish does not because it is holding on.

d. the nett force on the shark is always the same as that on the sucker-fish because they always have the same speed.

e. the drag from the sucker-fish on the shark means that the nett force on the shark is less than on the sucker-fish.

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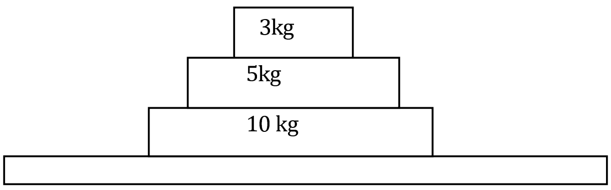
The blocks shown in the figure below are on a table. What is the nett force acting on the 5 kg block when the stack is:




**Question 9**

at rest?

a. 29.4 N downwards

b. 49 N downwards

c. 78.4 N downwards

d. 0 N

e. 19.6 N upwards

**Question 10**

being pushed to the right with constant velocity?

a. 29.4 N downwards

b. 49 N downwards

c. 78.4 N downwards

d. 0 N

e. 49 N to the right

## SECTION B: WRITTEN ANSWER QUESTIONS
## USE THE ANSWER BOOKLET PROVIDED

**Note:** Suggested times are given for section B as a general guide only. You may take more or less time on any question – everyone is different.

### Question 11

*Suggested Time: 20 min*

This question explores the characteristics of shadows formed by a variety of light sources.

Throughout this question you will be asked to draw diagrams as part of your answer. Where instructed please use the boxes on pages 2–3 of the answer booklet to draw these diagrams. Label all diagrams.

a) Point light sources emit light in all directions from a single point. They have no measurable size.

  (i) In the answer box on page 2 of the answer booklet, an object is drawn in front of a point light source. In this box draw a diagram of how the shadow forms, and what the shadow looks like on the screen.

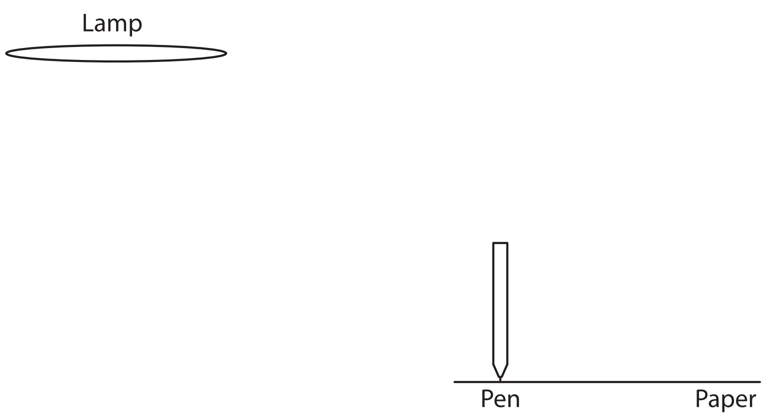
  (ii) If the object were at a distance from the light source of 1/3 the distance from the light source to the screen, how large would the shadow be compared to the object? Explain your answer using diagrams drawn in the box on page 2 of the answer booklet. Put any words needed in or near this box.

b) All real light sources, including the Sun and artificial sources, are extended sources rather than point sources. For example, at sunrise and sunset is it possible to see that the Sun is an extended source of light, circular in shape. Light is emitted in all directions from each part of an extended source.

  (i) Draw a diagram of how the shadows form and what the shadows of the object look like on the screen in front of an extended light source for the two set ups drawn in the answer box on page 2 of the answer booklet.

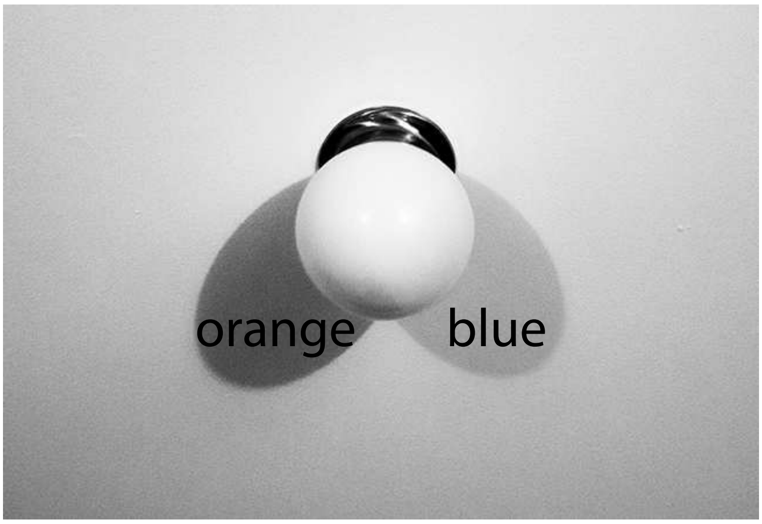
  (ii) Explain why shadows can be fuzzy-looking in the box on page 2 of the answer booklet.

  (iii) Given the setup below, draw the shadow of the pen on the diagram in the box on page 3 of the answer booklet.



c) Compact fluorescent light bulbs come in a range of slightly different colours. Some are described as ‘cool’ white and emit light which is more blue in colour, while others, described as ‘warm’ white, emit light of a more orange colour.

A room is lit by one or more lamps fitted with compact fluorescent bulbs. A shadow pattern forms on the ceiling near a ceiling lamp which is not turned on, as shown in the diagram below.




(i) Mark on the floor plan on page 3 of the answer booklet the positions of any operating lamps and the colours of their bulbs.

(ii) In the box on page 3 of the answer booklet, draw a diagram showing how the ceiling would appear from the door of the room. Indicate the colours of all regions of shadow.

d) A sheet of black cardboard with a very small round hole in its centre is held 10 cm above a white paved area outside at noon under a clear sky, and the image below is observed.

(i) Draw diagrams to explain how this image is formed in the box on page 3 of the answer booklet.

(ii) Would you expect to see the same thing on most other clear days? Explain why or why not in the box on page 3 of the answer booklet.

**Question 12**

*Suggested Time: 20 min*

Some elements have radioactive isotopes (radioisotopes) which can be used for medical imaging. A radioisotope is injected into the bloodstream, whence it is taken up by organs in the body. Areas of extremely high cell growth or repair such as tumours take up and retain this isotope much more efficiently than any other tissue. Thus imaging using radioisotopes can be used to indicate malignant tissue growth. Technetium-99m ($^{99m}$Tc) is one such radioisotope, which is used for imaging organs such as the thyroid, liver, kidneys, and brain. The half-life, the interval during which the number of atoms left of a radioisotope halves, of $^{99m}$Tc is $\tau_{1/2} = 6.01$ hours.

Rates of radioactivity can be measured in Curies (Ci), equivalent to $3.7 \times 10^{10}$ decays per second. For any radioisotope, the number of atoms, half-life and radioactivity are related by the formula

$$(\text{number of atoms}) = \frac{1}{\ln 2}(\text{half-life in seconds}) \times (\text{activity in decays per second}).$$

In this question, we examine a model of the process of $^{99m}$Tc uptake in a patient's cancerous thyroid glands. The patient is an otherwise healthy adult. In this model, $A = 10.0$ mCi of $^{99m}$Tc is injected into a vein in the patient's arm of radius $r_a = 1.00$ mm, enters the bloodstream, then enters each thyroid gland through an artery in the patient's neck of radius $r_n = 1.70$ mm.

Let the velocities of blood flow in the patient's arm and neck be $v_a = 3.00$ mm/s and $v_n = 40.0$ cm/s. Let the total blood volume of the patient be $V = 5\ \text{L} = 5 \times 10^{-3}\ \text{m}^3$, and let each thyroid gland (there are two) have volume $V_t = 9$ mL. The $^{99m}$Tc emits gamma rays of energy $E = 2.24 \times 10^{-14}$ J .
Give your answers both as formulae and numerically where applicable.

a) What is the concentration (in number of atoms per litre) of $^{99m}$Tc in the bloodstream after the injection?

b) Qualitatively, sketch the amount of $^{99m}$Tc in the thyroid as a function of time, starting from the time of injection.

c) The continuity equation in fluid mechanics states that the volume flow rate of fluid flowing through a pipe is constant. Consider the blood flow in the arm and neck of the patient - does the continuity equation hold in this model? Justify your answer with calculations, and use your knowledge of the body to explain why you would expect this result.

d) What is the initial rate of energy release due to gamma radiation emitted from a thyroid gland? In this and subsequent parts you may neglect the time taken for the thyroid glands to saturate with $^{99m}$Tc.

e) A scan is taken over $t_s = 10.0$ minutes. If the total energy detected by the scanner exceeds $E_{\text{min}} = 5 \times 10^{-4}$ J, an image appears due to radioactivity in a thyroid gland. Approximately how much time will elapse before radioactivity is no longer detected in a scan?

## Question 13

*Suggested Time: 20 min*

After some time spent pondering the workings of the universe, John says to Mary, "Energy is always conserved." Mary, however, doesn't agree. She says to John that if two identical cars travelling at the same speed collide head-on, there is kinetic energy before the collision, but no kinetic energy after. The two continue their disputation over a cup of tea, and await your assistance at the end of this question.

The *momentum* of an object of mass $m$ moving with velocity $\mathbf{v}$ is

$$\mathbf{p} = m\mathbf{v} \ .$$

The (vector) sum of the momenta of all of the objects in any collision is the same before and after the collision. In this question, a positive velocity indicates motion to the right.

a) Two hard particles $m$ and $M$ collide head-on. They have initial velocities $\mathbf{v}$ and $\mathbf{V}$ respectively (so $\mathbf{V}$ is negative). If the collision is *elastic*, the kinetic energy is conserved, and the velocities of the particles after colliding are

$$\mathbf{v}' = \frac{(m-M)\mathbf{v}+2M\mathbf{V}}{m+M}$$
$$\mathbf{V}' = \frac{(M-m)\mathbf{V}+2m\mathbf{v}}{m+M}$$

(i) What do these equations become for $m = M$? Give an example of such a collision.

(ii) Approximate these equations for $M \gg m$. Give an example of such a collision.

b) Find the fraction of the kinetic energy which is lost if two gunky blobs of masses $m = 0.50$ kg and $M = 3.0$ kg with velocities $\mathbf{v} = 0.50\ \mathrm{m\,s^{-1}}$ and $\mathbf{V} = -0.10\ \mathrm{m\,s^{-1}}$, collide head-on and the final velocity of the gunky blob with mass $m$ is $\mathbf{v}' = -0.25\ \mathrm{m\,s^{-1}}$.

c) In the case where the collision is completely inelastic, the gunky blobs stick together to form a superblob of total mass $M' = (M+m)$. If $m = 0.50$ kg, $M = 2.5$ kg, $\mathbf{v} = 0.50\ \mathrm{m\,s^{-1}}$ and $\mathbf{V} = -0.10\ \mathrm{m\,s^{-1}}$, determine the fraction of kinetic energy lost during the formation of the superblob.

d) Is either John or Mary from above correct, and how can their statements be reconciled?

**Question 14**

*Suggested Time: 40 min*

Friction is the force between surfaces that acts to prevent their relative motion. It acts along the plane of the surface. The part of the contact force which acts perpendicular to the plane of the surface is the normal force. Static friction, present when two bodies are at rest relative to each other, takes any value necessary to balance other forces up to a maximum given by

$$\mathbf{F} = \mu \mathbf{N} \ ,$$

where $\mu$ is the *coefficient of static friction*.

Friction can be used to make eating pineapple an exciting experience. Consider a large cube of pineapple sitting on a chopping board. One end of the board is on the edge of the bench, and the other end is raised, so that the board is inclined at an angle $\theta$ to the bench.

a) Draw a free body diagram showing the forces acting on the pineapple.

b) The board is gradually tilted up until the cube of pineapple begins to slide inexorably toward the waiting mouth at bottom of ramp. Show that $\mu = \tan\theta$.

Cubes of pineapple are, regrettably, perishable goods, and we apologise that we were unable to ship one to you for the purposes of this examination. Therefore, the next part of this question will use the (admittedly poor) substitutes of paper and pencil. When you draw on paper with a lead pencil, you coat the paper with a graphite mixture.

c) The coefficients of static friction differ between different pairs of surfaces. Using the ideas presented above and the theory you have derived, devise and perform an experiment to find the *difference* between A) the coefficient of static friction between paper and paper and B) the coefficient of static friction between paper and graphite mixture.

**Equipment:** You may tear out the next three leaves of this question book to use as equipment. Some suggested folds are marked to help you create some useful apparatus, but the choice of what to do with your paper is up to you. Along with the paper of these three pages, you may also use the lead pencil which you brought into this exam, and a ruler. Remember to be safe when using any equipment – make sure you don't injure yourself or other people (or your pencil or ruler).

**What is required:** Write out the method that you are going to use in detail and justify why you have chosen it, along with any modifications you make along the way. State your results, and any processing you do of them, and evaluate your answers.

**Important:** *the credit in this question is primarily for your method, how you would calculate the results, and your observations of what works and doesn't as you try your experiment. The numeric answers are a small part, and you should not be concerned if you are unable to get them – we are interested in your thought processes, designs and observations.*

As a final note, although this be in lieu of a pineapple-based experiment, do not attempt to eat any of your equipment.

This work of ours is done: there are no questions more.
Your work has just begun: enjoy it, we implore!

The remaining pages in this booklet are for use as equipment for Q14.

This page may be torn out and used as equipment.
A4 paper is 297 mm long by 210 mm wide.

fold 1

fold 2

fold 2

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***Integrity of Competition***

*If there is evidence of collusion or other academic dishonesty, students will be disqualified. Markers' decisions are final.*