Surname	Centre Number	Candidate Number
Other Names		2

GCE A LEVEL – NEW

1420U30-1

S17-1420U30-1

PHYSICS – A2 unit 3
Oscillations and Nuclei

THURSDAY, 15 JUNE 2017 – MORNING

2 hours 15 minutes

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1.**	**11**	
	2.	**10**	
	3.	**15**	
	4.	**13**	
	5.	**18**	
	6.	**13**	
Section B	**7.**	**20**	
	Total	**100**	

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ADDITIONAL MATERIALS

In addition to this examination paper, you will require a calculator and a **Data Booklet.**

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen.

Write your name, centre number and candidate number in the spaces at the top of this page.

Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space use the continuation page(s) at the back of the booklet taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

This paper is in 2 sections, **A** and **B.**

Section **A**: 80 marks. Answer **all** questions. You are advised to spend about 1 hour 35 minutes on this section.

Section **B**: 20 marks; Comprehension. You are advised to spend about 40 minutes on this section.

The number of marks is given in brackets at the end of each question or part-question.

The assessment of the quality of extended response (QER) will take place in question **4**(*a*).

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SECTION A

Answer **all** *questions.*

1. *(a)* Describe an experiment that uses various absorbers to identify the type(s) of radiations emitted by a radioactive sample. Justify all steps in the experiment. [4]

(b) A radioactive sample of material has a half-life of 11.4 days and an initial activity of A_0. Determine:

(i) the decay constant; [2]

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(ii) the activity of the sample after 57.0 days in terms of A_0; [2]

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(iii) the **percentage decrease** in the number of nuclei in the sample after 57.0 days. [3]

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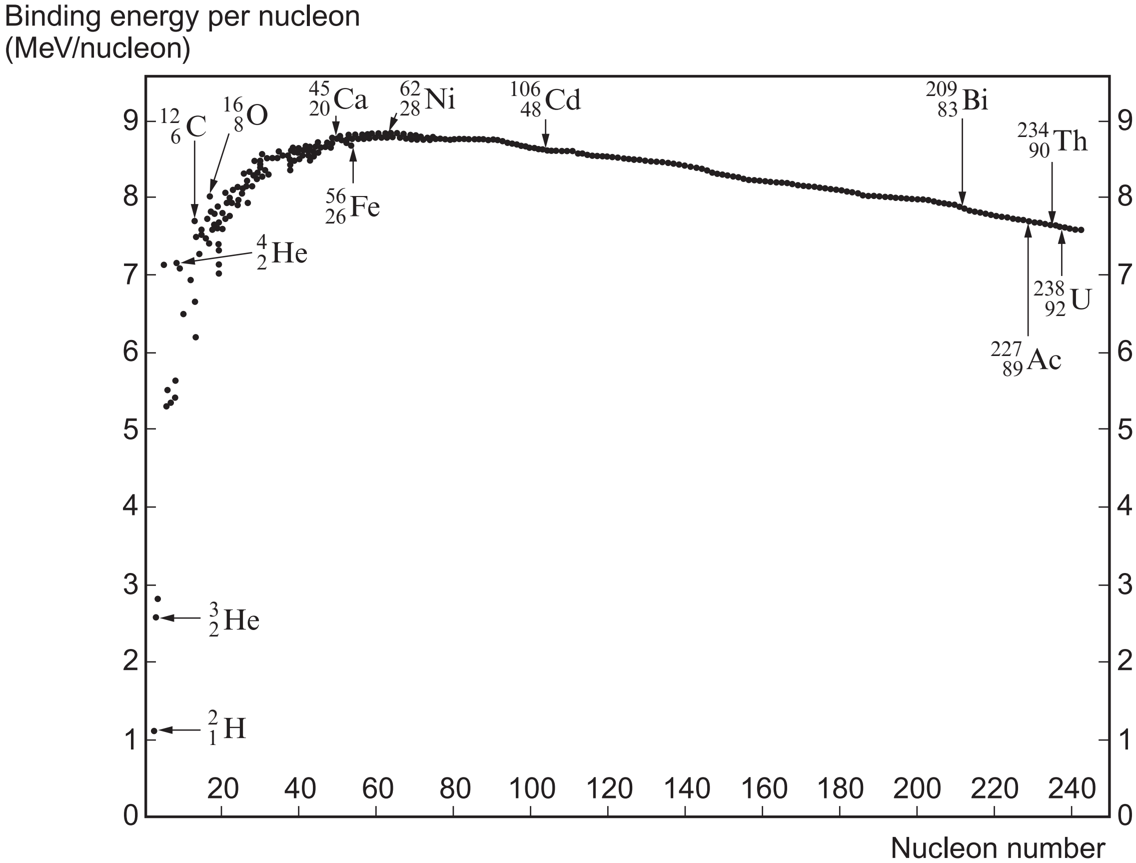
2. *(a)* Nuclear energy can be released by fusion or fission. Describe these processes by considering the graph of the binding energy per nucleon plotted against the nucleon number. [4]



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(b) The fusion of hydrogen to helium in the Sun may be represented by:

$$4\,{}^{1}_{1}\mathrm{H} + 2\mathrm{e}^{-} \rightarrow {}^{4}_{2}\mathrm{He} + 2\,\nu_{e}$$

Particle	Mass / u
${}^{1}_{1}\mathrm{H}$	1.00728
${}^{4}_{2}\mathrm{He}$	4.00151
e^{-}	0.00055
ν_{e}	0.00000

1 u = 931 MeV

Calculate the energy released in this reaction in MeV. [3]

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(c) Nuclear power has played a role in the generation of electricity in Wales. Wylfa Newydd on Anglesey may feature in further developments. Indicate a benefit and an issue that may arise from such projects and discuss their relative importance. [3]

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3. *(a)* The first law of thermodynamics is given by:

$$\Delta U = Q - W$$

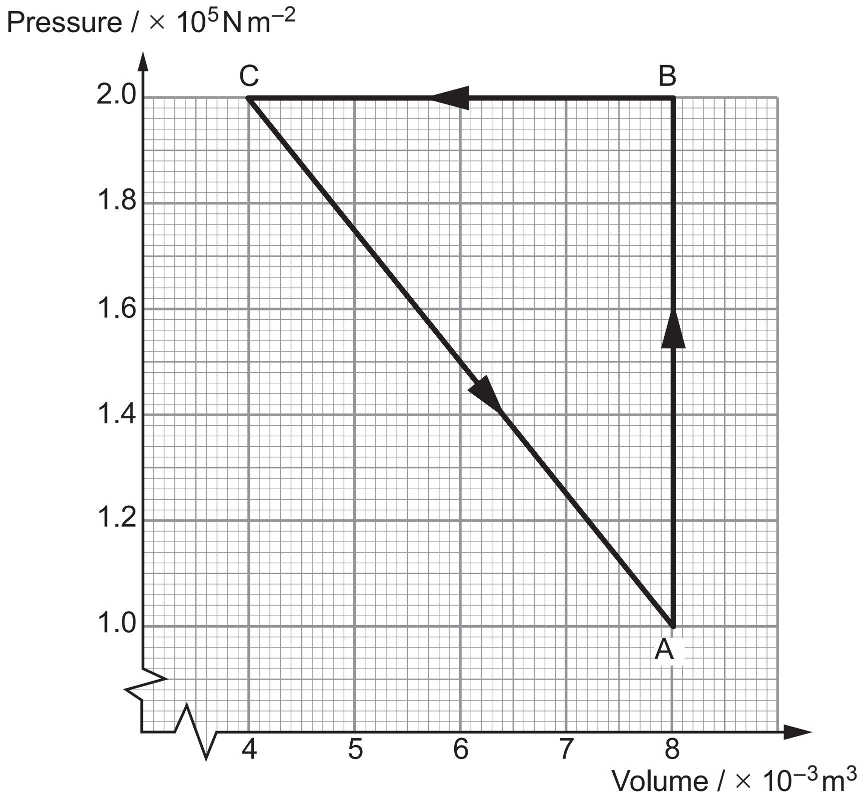
State what is represented by: [3]

ΔU ....

Q ....

W ....

(b) A fixed mass of gas is taken around the closed cycle A → B → C → A.



(i) Complete the table by describing each process in terms of pressure and volume. The description for process A → B is already inserted. For each process state if any work is done, and if so indicate if it is done *on* or *by* the gas. *No calculations are required.* [5]

Process	Description of process	Work done on / by gas (if any)
A → B	Increase in pressure at constant volume	
B → C		
C → A		

(ii) Determine the net work done on the gas during the entire cycle. [2]

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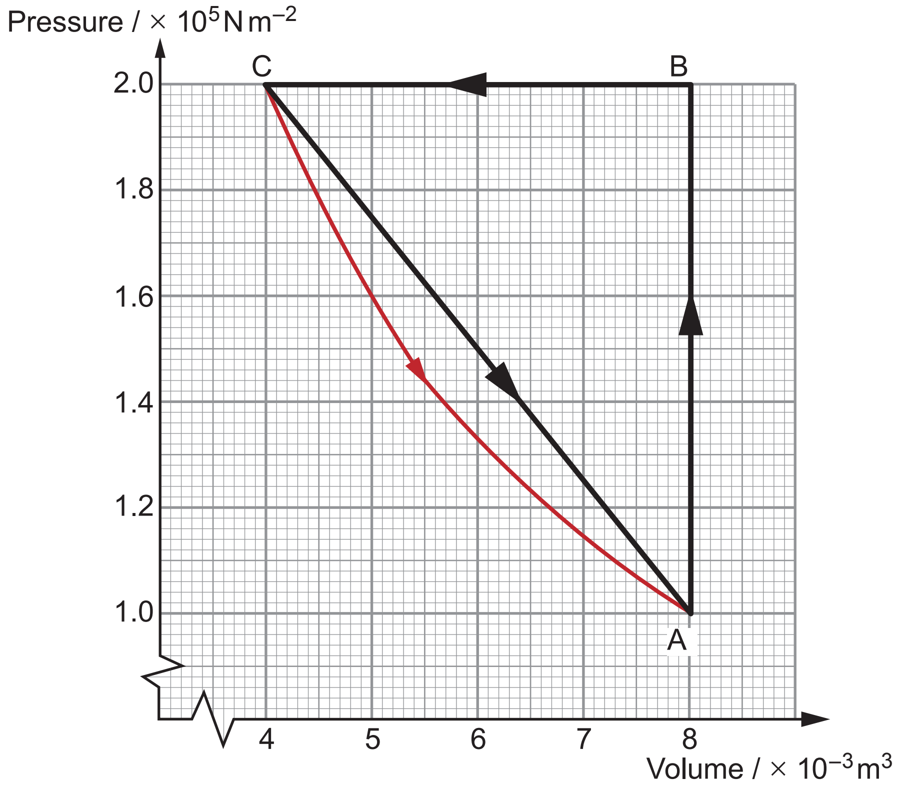
(c) The same mass of gas is taken around the cycle A → B → C → A for a second time. For this cycle the temperature is kept constant between C and A. The new path from C to A is shown in red on the graph below, together with the original path.



(i) Show that the temperature is constant along the new path from C to A. [3]

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(ii) Estimate the difference in the net work done in the two cycles. [2]

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4. *(a)* Heat is supplied to an ideal gas in a sealed container of fixed volume. Explain carefully the physical processes that cause an increase in the **temperature and pressure** of the gas. [6 QER]

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(b) A container of fixed volume contains oxygen gas at a temperature of 293 K.

(i) Five oxygen molecules have speeds 400, 425, 450, 550 and 625 $m\,s^{-1}$. Determine their rms speed. [2]

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(ii) Using an appropriate calculation, determine whether or not the rms speed calculated in part *(b)*(i) is consistent with the expected rms speed of the molecules of the gas at this temperature. (Relative molecular mass of oxygen gas = 32.) [3]

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(iii) If the gas in the container is heated and the pressure of the gas increases by 20% of its initial value, determine the rms speed of the molecules of the gas. [2]

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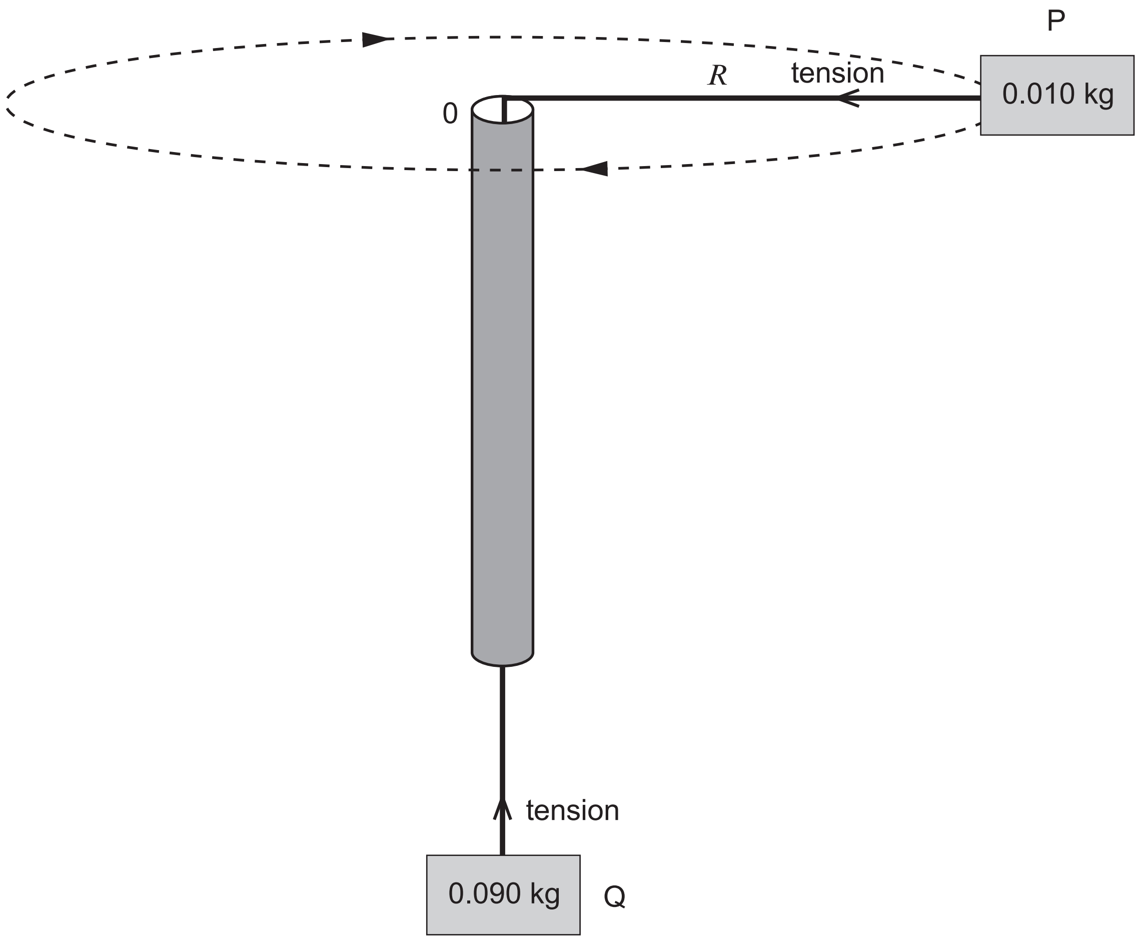
5. A piece of string is threaded through a hollow narrow cylinder. Two small objects, P and Q, with masses 0.010 kg and 0.090 kg respectively are attached to the ends of the string, as shown.

A student holds the cylinder and sets the 0.010 kg mass rotating in a horizontal circle of radius R, which is kept constant at 0.50 m. The time for 10 rotations is recorded. The tension in the string provides both the centripetal force on P and an upward force to hold Q in equilibrium.

The measurement is repeated for different values of R. All measurements are recorded in the table overleaf.



(a) Show that the speed, v, of mass P for each measurement is given by:

$v = \dfrac{2\pi R}{T}$ where T is the period of rotation. [1]

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(b) Complete the table. [4]

R / m	Time for 10 rotations / s	Period T / s	v / m s^{-1}	v^2 / m^2 s^{-2}
0.50	4.7			
0.60	5.2			
0.70	5.6			
0.80	6.0			
0.90	6.3			

(c) (i) Assuming that OP is horizontal, write an equation relating the centripetal force to v and R. [2]

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(ii) Hence, by using the equation for the forces acting on mass Q, show that:

$$v^2 = 9g\,R$$

where g is the acceleration due to gravity. [3]

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(d) (i) Use the data in the table to plot a graph of v^2 (y-axis) against R (x-axis). [4]

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(ii) Determine a value for g. [3]

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(iii) Suggest a way in which the experiment can be improved. [1]

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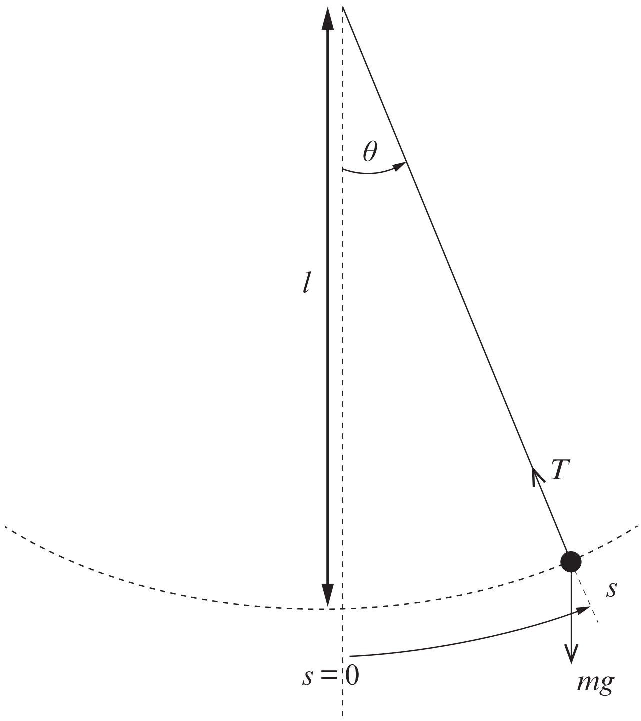
6. *(a)* The pendulum in the figure below has a small bob of mass, m, suspended at the bottom of a light string of length, l. The string is shown at an angle, θ, to the vertical and the mass, m, is at a distance, s, along the arc. The forces acting on the mass are shown.



(i) Name the **two** forces acting on the mass. [1]

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(ii) By considering these forces show that:

resultant force component on the mass along the arc = $-\,mg\ \sin\theta$

You may add to the diagram if you wish. [3]

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(iii) If the oscillation is small so that $\sin\theta \simeq \theta$ show in clear steps that the acceleration along the arc may be written as: [2]

$$\text{acceleration} = -\frac{gs}{l}$$

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(iv) Discuss whether the equation in part *(a)*(iii) satisfies the definition of simple harmonic motion. [2]

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(b) A small mass oscillates at the lower end of a pendulum of length 1.20 m.

(i) Determine its:

I. period; [2]

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II. frequency. [1]

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(ii) If the maximum displacement angle of the mass is 0.067 rad, justify the use of simple harmonic motion in part *(b)*(i). [2]

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SECTION B

Answer **all** *questions.*

Read through the following article carefully.

Lasers in Outer Space

Paragraph

Einstein's theory of stimulated emission, published in 1916, laid the foundation for lasers but it took humans another 44 years before the first successful ruby laser was produced. However, seven years beforehand a maser had been produced. This is similar to a laser but involves microwaves instead of light – **m**icrowave **a**mplification by **s**timulated **e**mission of **r**adiation. 1

It turns out that masers are easier to build than lasers because the lifetime of metastable energy levels tends to be proportional to $\frac{1}{\text{frequency of radiation}}$. 2

The ingenuity of humankind is often marvelled upon when such complicated devices as lasers and masers are used in devices such as DVD players and atomic clocks. However, nature itself is somewhat more modest – natural masers have been produced for billions of years in the atmospheres of stars, comets, star-forming regions, supernova remnants and even super massive black holes. And all this time the Universe has kept quiet about its technological achievements. 3

Essentially what happens in star masers is this – light and explosions from stars excite nearby gas regions. In these nearby gases, light and collisions lead to high energy levels becoming populated by electrons. Some of these higher energy levels will be metastable, setting up a maser amplifying region. As in any laser, the process has to start with a spontaneous emission accidently shooting off in the correct direction, but afterwards, stimulated emission takes over and the maser beam starts towards infinity; infinity is stretching the truth a bit but it does sound good. In reality the intensity of the maser beam increases rapidly and the beam propagates at the speed of light as em radiation tends to do. 4

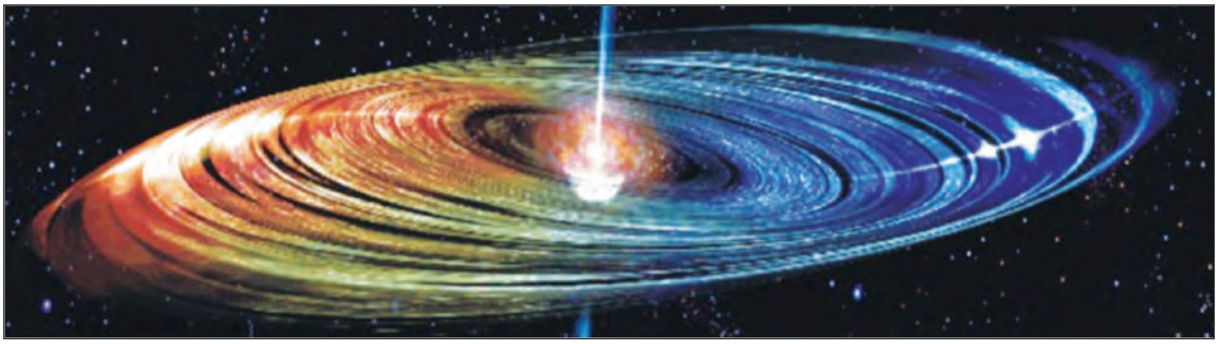

Diagram 1

In all fairness to humans, there is one aspect of laser design that nature has not succeeded in producing by itself and that is the resonant cavity of a laser. Multiple passes through a laser amplifying medium improves the quality of laser operation immensely. This is achieved among humans using two mirrors but as yet this technological advancement seems to be missing in gas regions around stars. 5

Paragraph

Although a resonant cavity seems to be missing in natural masers there does seem to be a high degree of beaming. Small differences across the irregularly shaped maser cloud disk lead to vast differences in intensity due to exponential gain. The directions in the gas disk that have a longer length of population inversion will appear much brighter (as the increased maser amplification leads to an exponential increase). The majority of the radiation will emerge along this line of greatest length in a "beam"; this is termed *beaming*. Not quite as good as a laboratory laser cavity but pretty impressive for a seemingly random gas cloud. 6

Megamasers is the term used for water masers in the gas cloud around black holes. 7

Most large galaxies with a nucleus and a bulge have, at their centres, a supermassive black hole. When the black hole is actively accumulating matter, it releases a tremendous amount of energy, and the galaxy is said to have an active nucleus. Buffered by the dust in the flow of matter into the black hole, molecules can survive there and get energised by collisions with other molecules and dust particles. Water molecules are common in this environment, and they can emit maser radiation. A water maser can shine a beam of microwaves at a very specific frequency, 22.235 GHz, which corresponds to microwaves about 1 cm in wavelength. The primary reason megamasers have been studied in detail is that they make excellent tools to help us understand the environment around black holes. Small changes in the detected frequency of the masers, owing to the Doppler effect, mean that we can determine the line-of-sight velocity of maser clouds very precisely. All this means that the mass of black holes can be determined 20 times more accurately. 8

Another primary science goal that we can address with studies of water megamasers is measuring distances to galaxies. Measuring distances is a notoriously difficult problem in astronomy, and one of the most important. By analysing the internal dynamics of water maser systems, we can measure the rotation velocity, v, of maser clouds as they orbit the black hole from the Doppler shift of the maser lines. We can also measure the centripetal acceleration, a, of maser clouds by observing how the Doppler shift velocity changes over time. Using the simple relation for centripetal acceleration: 9

$$a = \frac{v^2}{r}$$

we can then calculate the radius of the gas 'disk' (see below) orbiting the black hole.

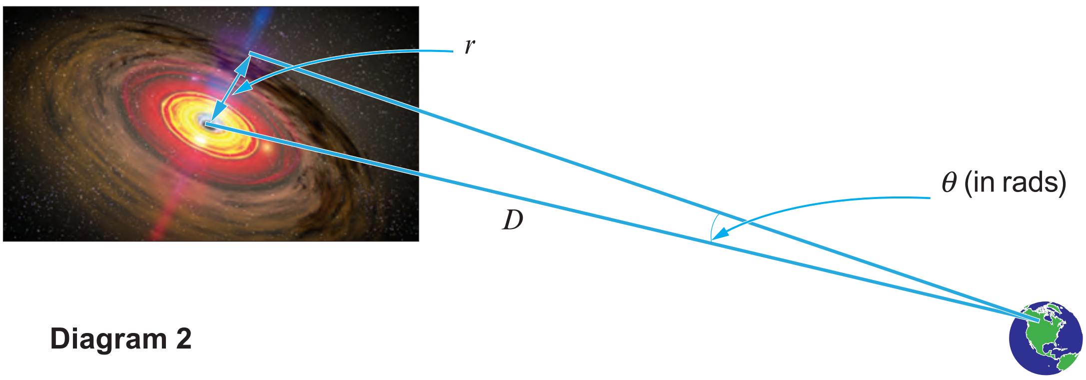

Diagram 2

We can also measure the angular size (θ) of the gas disk (in radians). Given the angular size (θ) and the radius, r, of the gas disk, we can obtain the distance, D by assuming that the angle (θ) is small. The simplicity of this method is remarkable and gives reliable results that are not dependent on controversial or unproven theories. In fact, the results obtained thus far from a couple of suitable galaxies with megamasers leads to a Hubble constant of (68.9 ± 7.1) km s^{-1} Mpc^{-1}. 10

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7. Answer the following questions in your own words. Direct quotes from the original article will not be awarded marks.

(a) In your own words explain what a megamaser is and how it works. (See paragraphs 1, 4, 7 and 8.) [5]

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(b) If the lifetime of a metastable level leading to visible light is 2 μs, estimate the lifetime of a 22.235 GHz maser transition. (See paragraph 2.) [3]

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(c) The recessional velocity of the galaxy used in paragraph 10 is 3 300 km s^{-1}. Use Hubble's law to calculate the distance of the galaxy in Mpc. (N.B. use the value of H_0 in paragraph 10. There is no need to change the units.) [2]

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(d) What does the author mean by "We can also measure the centripetal acceleration, a, of maser clouds by observing how the Doppler shift velocity changes over time"? (See paragraph 9.) [3]

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(e) (i) Doppler shift measurements are obtained for a gas disk orbiting a black hole. The orbital velocity of gas around the black hole is measured as 410 km s^{-1} and the acceleration of the gas disk is measured as 6 km s^{-1} **per year**. Calculate the distance of this region of the gas disk from the black hole. (See paragraph 9.) [3]

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(ii) The angular size (θ) in radians of the gas disk is measured as 5.1×10^{-9} rad ± 10% and its distance from Earth is measured as 1.53×10^{23} m ± 10%. Evaluate whether or not these values are consistent with your calculation in part *(e)*(i). (See Diagram 2.) [4]

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END OF PAPER

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