PHYSICS SCHOLARSHIP 2015

CALCULATORS ARE NOT TO BE USED

Total marks available = 35

MOST OF THE MARKS IN THESE QUESTIONS ARE FOR SHOWING HOW WELL YOU CAN THINK. THE FINAL ANSWERS ARE LESS IMPORTANT THAN SHOWING THAT YOU CAN THINK AND WORK LOGICALLY.

You must show your working out at all stages and clearly state any assumptions that you are making.

Where you can, use powers of ten to show very big or very small numbers. For example $1{,}000{,}000 = 1 \times 10^6$

The following is an excerpt from Tom Morton-Smith's play *Oppenheimer*, currently in production at the Swan Theatre, Stratford. The play tells the story of the Manhattan Project, a research and development project which produced the first atomic bombs during World War II.

There was a Maharaja who had a great passion for chess. Travelers, as they passed through his court, were invited to his throne room and challenged to a game. One day a visiting sage appeared at the palace gates. He was welcomed and brought before the king. 'Do you know chess?' 'I do.' 'Then let us play.' The sage smiled and politely inquired as to what his prize would be if he were to win. The Maharaja laughed and offered any reward that the old man could name. The sage modestly asked for a few grains of rice. 'How many grains?' enquired the king. 'Place one grain of rice on the first square of the chessboard, two on the next, four the next then eight, sixteen, and keep doubling the number of grains on every following square.' 'Very well.' And so they played. It was a hard fought game, but it did not go the way of the king. Having lost and being a man of his word the Maharaja ordered for a bag of rice to be brought to the chessboard. He placed one grain on the first square, two on the second, then four, eight, sixteen, thirty-two, sixty-four, 128, 256, 512, 1024, 2048, 4096 - I could do this all day. By the twentieth square the Maharaja required a million grains of rice. By the final sixty-fourth square he required more rice than had ever existed - enough to cover all of India with a layer one meter thick. Such an amount would require paddy fields covering twice the surface of the world — oceans included. The Maharaja was agog. It was at this point that the Lord Krishna shook off the image of the sage, revealing his true identity to the king. 'Now you are humbled before the power of exponential mathematics. A neutron enters an atom, splits it, three further neutrons are released and what you have is a chain reaction.

Question 1

How many grains of rice will there be on the fifth square? [1]

Question 2

Compare the number of grains of rice on the third square with the total number of grains of rice on the first two squares. Next, compare the number of grains of rice on the fourth square with the total number of grains of rice on the first three squares.

Which, of the following, will be greater (circle the correct answer)?

A The number of grains of rice on the 15^{th} square

B The total number of grains of rice on the first 14 squares of the board [1]

Question 3

Which is the first square to contain at least 1,000 grains of rice? [2]

Question 4

Line 14 of the passage states:

By the twentieth square the Maharaja required a million grains of rice

This refers to the total number of grains of rice up to and including the 20^{th} square.

Approximately how many grains of rice will there be on the 20^{th} square? [2]

Question 5

The total number of grains of rice required by the Maharaja is indeed large – approximately eighteen million million million.

a) If this number were to be written as "18" followed by a string of zeros, how many zeros would there be? [1]

b) Given that 1,000,000 can be more concisely expressed "1×10^6", express the total number of grains in a similar form. [2]

Question 6

Describe method to determine the mass of a single grain of rice. You may wish to refer to equipment, a calculation, and assumptions. [3]

Question 7

There are approximately 50,000 grains of rice in a 1kg bag.

What is the mass of a single grain (in grams)? [1]
What is the mass of a single grain (in kilograms)? [1]

Question 8

A 1kg bag of rice has a volume of approximately 1.25×10^{-3} m^3.

Show that the density of dry rice is approximately 800 kg/m^3. [2]

Question 9

India has an area of approximately 3×10^{12} m^2

What is the volume of a one-metre-deep pile of rice covering the surface of India? [1]

Question 10

Using the information in Question 8:

Calculate the mass of a one-metre-deep pile of rice covering the surface of India [2]

Question 11

Using the information in Question 7:

Determine how many grains of rice would be needed for a one-metre-deep pile of rice covering the surface of India. [2]

Question 12

As explained in Question 5, the total number of grains of rice required by the Maharaja is approximately 18 million million million.

Lines 15 and 16 of the passage state:

> *By the final sixty-fourth square he required more rice than had ever existed - enough to cover all of India with a layer one meter thick*

Based on your calculations from the previous page, do you agree with lines 15 and 16 of the passage? Explain your answer. [2]

Question 13

The final lines of the passage provide a very brief overview of the process called Nuclear Fission:

> *A neutron enters an atom, splits it, three further neutrons are released and what you have is a chain reaction.*

The following nuclear equation describes this process:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{90}_{36}Kr + ^{143}_{56}Ba + ^{1}_{0}n + ^{1}_{0}n + ^{1}_{0}n$$

U=uranium Kr=krypton Ba=barium n=neutron

The nucleus of an atom contains two types of particle, called **protons** and **neutrons**.

The number below the nuclear symbol indicates the number of protons in the nucleus. The number above the nuclear symbol indicates the combined number of protons and neutrons in the nucleus.

eg Carbon: $^{14}_{6}C$

The nucleus comprises 6 protons and 8 neutrons

a) How many neutrons are there in the nucleus of $^{235}_{92}U$? [2]

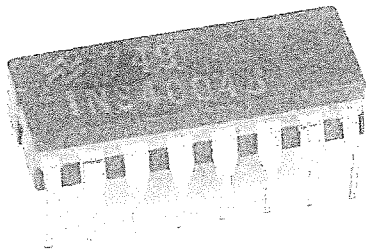
b) $^{235}_{92}U$ is the symbol for Uranium-235.

Another type of Uranium nucleus (called Uranium-238) has three extra neutrons. What is the symbol for Uranium-238? [2]

Question 14

In 1965, Gordon E. Moore predicted that the number of transistors in computers' microprocessors would double every two years (much like the grains of rice on the Maharaja's chessboard). His prediction/observation is known as Moore's Law.

Here is the Intel 4004, the first commercial microprocessor (introduced in 1971):



It contained approximately 2,000 transistors.

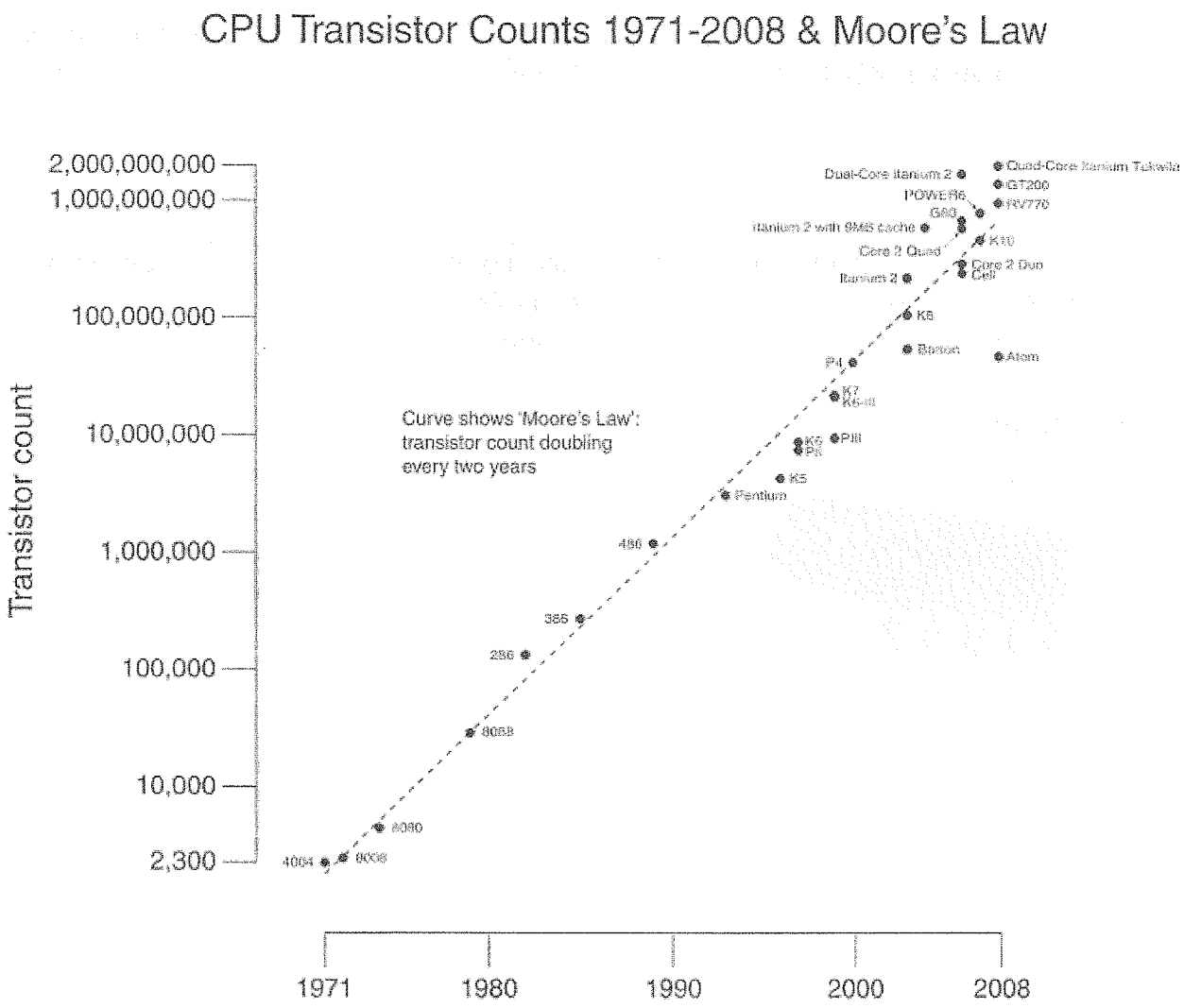
a) Show that, according to Moore's Law, a microprocessor introduced in 1979 should have contained approximately 30,000 transistors. [3]

b) Using the following table, name the processor that most neatly fits with the Moore's Law prediction of (a). [1]

Processor	Transistor count	Date of introduction
Intel 4004	2,300	1971
Intel 8008	3,500	1972
MOS Technology 6502	3,510[6]	1975
Motorola 6800	4,100	1974
Intel 8080	4,500	1974
RCA 1802	5,000	1974
Intel 8085	6,500	1976
Zilog Z80	8,500	1976
Motorola 6809	9,000	1978
Intel 8086	29,000	1978
Intel 8088	29,000	1979
WDC 65C02	11,500[6]	1981

Question 15

The following plot provides information on microprocessors introduced between 1971 and 2008 (showing transistor count vs year of introduction):



a) In what year was the Pentium "P4" introduced? [1]

b) How many transistors are there in the AMD "K8"? [1]

c) Of the five microprocessors introduced in 2006, which most closely obeyed the Moore's Law trend of previous years? You will need to look closely at the graph to answer this question. [2]