The Michael Smith Science Challenge 2007: Analysis

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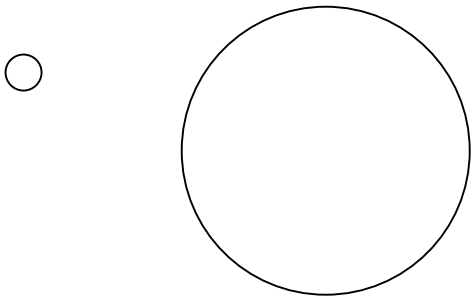
Introduction

This is the fifth Michael Smith Science Challenge run nationally, and the third in the non-multiple choice format. We have consciously included many different types of question: representation-translation, short answer, calculational, proportionality and estimation. We have again striven to make the questions as general as possible to avoid problems with differences in individual provincial curricula.

The maximum possible mark was 60; the mark obtained by the top student this year was 48; 10% of students scored 30 or more; 25% of students scored 22 or more. A total of 538 students wrote the examination.

The Examination

Question 1.



(a) The area of the larger circular disc above is ___ times larger than that of the smaller circular disc.

Let the circles above represent spheres rather than discs:

(b) The surface area of the larger sphere above is ___ times larger than that of the smaller sphere.

(c) The volume of the larger sphere above is ___ times larger than that of the smaller sphere.

Solution and marking scheme.

Diameters are 4.5mm and 36mm, i.e. a factor of 8

(a) Best answer $8^2 = 64$ *(max 2 marks)*
2 marks for anything between 36 and 100 inclusive; 1 for 25-36, 100-144

(b) Best answer 64 *(max 2 marks)*
2 marks if equal to (a) and (a) between 36 and 100
1 mark if between 25 and 144 and not equal to (a)

(c) Best answer $8^3 = 512$ *(max 2 marks)*
2 marks if equal to (a) and/or (b) raised to the 3/2 power
1 mark if not but answer between 125 and 1728

Student Responses and Remarks

This problem tests the students' understanding of proportionality and how any and all areas and volumes scale with the square and the cube respectively of any and all linear scales (e.g. radius, diameter, circumference). Undergraduate science students often have great difficultly with this concept. More than half the Science 10 students writing this examination recognized that the area of a circle scales as the square of the radius or diameter, which is not a trivial achievement. More that 1/3 also realized that the area of a sphere scales the same way, which is yet more difficult. More than ¼ made the last step of scaling the volume of the sphere with the cube of a linear dimension.

Many answers to (b) were the square of that for (a). It is not clear whether this was due to a simple misreading of the question or the common confusion between the circumference and area of a circle.

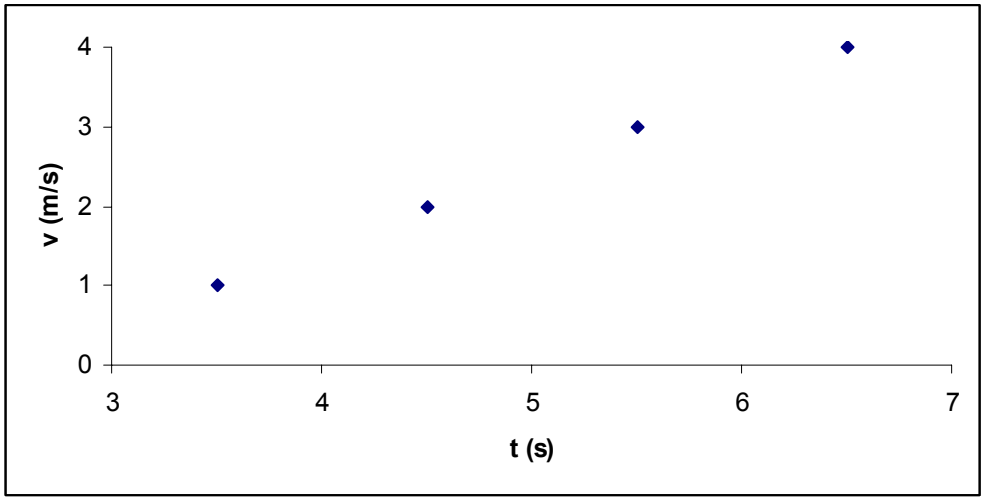
The mean score was 2.6/6; the maximum achieved score was 6/6 and the minimum 0/6.

Question 2. Here's a table of an object's position as a function of time. It is moving in one dimension only. Sketch a graph of your best estimate of its *velocity,* as a function of time.

t (s)	x (m)
3.0	1.0
4.0	2.0
5.0	4.0
6.0	7.0
7.0	11.0

Solution and marking scheme.

Best answer *(max 6 marks)*



0 marks if x vs. t plotted, or $v = x / t$
No more than 4 marks if data are invented, e.g. (0,0).
At least 4 if $v = \Delta x/\Delta t$ recognized
1 mark off if points at integer times, or no axis labels.

Student Responses and Remarks

More than half of all students simply plotted the position versus time and labelled the graph "velocity". It is hard to say whether this was just a rushed misreading of the question and an assumption that it was a simple graphing question, or a genuine lack of understanding of the word "velocity". One student wrote "We haven't done velocity" on his paper. We may possibly have received a different response if we had used the word "speed".

A much smaller number of students divided x by t and called *this* velocity; we had anticipated this (it is the majority response – 80% – of first-year science undergraduates to this same question!), which is why we did not start with $(x,t) = (0,0)$. Only a few percent of students divided the *difference* in position by the *difference* in time, which is correct.

The mean score was 0.4/6; the maximum achieved score was 6/6 and the minimum 0/6.

Question 3. Describe the cycling of carbon in the biosphere and the role photosynthetic organisms play. Use 20 words or less, and maybe a simple diagram.

Solution and marking scheme.

One mark for each of these *sources* (*max 3*);
-cellular respiration/animal life
-animal/plant decay
-human industry/transportation
-agriculture

One mark for each of these *sinks* (*max 3*);
-photosynthesis/plant life
-marine organisms
-solution in oceans/lakes

No marks off for incorrect items
Zero for irrelevancies

Student Responses and Remarks

This question was intended to assess how much students understand about the *cycling* of carbon in the biosphere, and how it is both a natural and anthropogenic process. This is why, to gain more than half marks, they had to identify both sources and sinks of carbon. A little over half the students named at least one of each, typically photosynthesis and cellular respiration, and about a quarter gave an essentially complete answer.

The mean score was 2.1/6; the maximum achieved score was 6/6 and the minimum 0/6.

Question 4. Two healthy parents know from blood tests that each parent carries a recessive allele responsible for a disease.

(a) If their first three children have the disease, what is the probability that their fourth child will not?

(b) Assuming that they have not yet had a child, what is the probability that, if they have four children, all four will have the disease?

Solution and marking scheme

(a) Best answer 3/4; the first 3 children are irrelevant to the calculation (*3 marks*)

1 mark for 1/4

(b) Best answer $(¼)^4$ = 1/256 or 0.39% (*3 marks*)

1 mark for recognizing a multiplicative solution

Student Responses and Remarks

This question tested knowledge of basic genetics, mathematical probability, and, crucially, the ability to read a word question carefully and translate it into numerical form. About 25% of students found the correct answer for (a) and a similar number misread the question (presumably) and got ¼. A slightly smaller fraction got (b) correct. About a quarter of responses for both (a) and (b) were clearly guesses; the rest were left blank.

The mean score was 1.7/6; the maximum achieved score was 6/6 and the minimum 0/6.

Question 5. Four cubes of identical size and mass are made of the following:

- Aluminum painted white
- Aluminum painted black
- Concrete painted white
- Concrete painted black

(a) These blocks are left for several hours on a roof on a sunny summer day. Which one(s) has(have) the highest temperature? Lowest temperature? Or are they all the same?

(b) These blocks are left for several hours in boiling water. Which one(s) has(have) the highest temperature? Lowest temperature? Or are they all the same?

(c) These blocks are left for several hours in boiling water. Immediately after being pulled out, which one(s) *feel* the hottest to your touch? Coolest? Or are they all the same?

Solution and marking scheme

(a) Best answer: both black highest, both white lowest (*2 marks*)
1 mark for selecting one black and one white

(b) Best answer: all same (*2 marks*)
Zero for any other answer

(c) Best answer: both Al hottest, both concrete coolest (*2 marks*)
1 mark for selecting one Al and one concrete

Student Responses and Remarks

The physics behind this problem is that (a) colour determines the absorption of solar radiation, (b) objects left in thermal conductive contact with surroundings of a given temperature will attain that temperature, regardless of their various properties, and (c) thermal conductivity determines how hot or cool objects of the same temperature feel to the touch.

About 20% of students got (a) correct and 40% for both (b) and (c). This is a little surprising as we considered (c) to be the hardest question, (a) being the subject of common experience and (b) amenable to anyone who has an idea of the meaning of temperature.

The mean score was 2.9/6; the maximum achieved score was 6/6 and the minimum 0/6.

Question 6. For many, hydrogen is considered to be the fuel of the future. Fill out as best you can the following table of advantages and disadvantages that hydrogen has compared to gasoline.

Advantages	Disadvantages
1	1
2	2
3	3
4	4
5	5

Solution and marking scheme

One mark for each of these *advantages* (max 3):
-burns to water only
-high energy density ("lighter")
-unlimited supply ("common")
-no CO_2 / greenhouse gases

One mark for each of these *disadvantages* (max 3):
-has to be produced (energy storage, not a source)
-explosive
-hard to store/cryogenic
-underdeveloped technology

No marks taken off for wrong items
Zero marks for irrelevancies and vagaries that did not indicate any understanding - like "less pollution", "clean", "environmentally friendly", "less global warming" etc.

Student Responses and Remarks

Given the hype surrounding hydrogen as a "fuel", we wondered what level of appreciation Science 10 students had about its advantages and disadvantages. Most students wrote down at least one of each, but most of the responses were too vague to warrant a mark in a science contest.

Approximately 3% of students wrote down three reasonable advantages and three reasonable disadvantages.

The mean score was 2.3/6; the maximum achieved score was 6/6 and the minimum 0/6.

Question 7. According to the bill I received from the gas company I burnt an energy equivalent of 100GJ of natural gas to heat my home last year. Assuming natural gas is methane (CH_4), and it produces 50MJ of heat per kg burnt: what mass of carbon dioxide (CO_2) did I produce in heating my home last year?

Solution and marking scheme

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$(100 \times 10^9) / (50 \times 10^6) = 2000$ kg of CH_4 burnt

$(2000 \times 10^3$ g) / (12 + 4 g/mol) = 1.25×10^5 moles of CH_4 burnt

$(1.25 \times 10^5) \times (1\ CO_2 / 1\ CH_4) \times (16 \times 2 + 12) = 5.5 \times 10^6$ g CO2

$(5.5 \times 10^6) / (10^3) = 5500$ kg of CO_2 produced.

Quick route to solution: 2000kg x 44/16 = 5500kg CO_2 produced.

Best answer 5.5t or 5500kg (6 marks)

-2 for simple errors like g/kg conversion, not knowing "G" or "M" if everything else right.

Student Responses and Remarks

This question is an exercise in domestic physical chemistry, and of the type which is crucial to assessing one's own contribution to global climate problems. But for calculational slips, this question was reasonably done by many students. Many of the errors were caused by the prefixes k, M and G, which we feel are in such widespread use now (i.e. not restricted to "science") that students should know what they mean. Other common errors were in the balancing of the chemical reaction. About ¼ of all students left the page blank.

The mean score was 2.3/6; the maximum achieved score was 6/6 and the minimum 0/6.

Question 8. Estimate, roughly, how many molecules of H_2O fell on Canada last year in the form of snow and rain. Show your work and what assumptions you make.

Solution and marking scheme

1 mark for a reasonable estimate of Canada's area (10M sq km, within a factor 10 either way)
1 mark for a reasonable guess at precipitation (0.1m to a few m liquid equivalent)
1 mark for putting these together for the right volume
1 mark for getting water density (1000kg/m^3, within a factor 10)
1 for converting to molecules correctly (divide by 18 x 1.67×10^{-27}kg)

1 for a final answer within a factor 100 of 3×10^{42}.

Student Responses and Remarks

This classical "Fermi question" is all about getting an unguessable answer by synthesizing reasonable estimates of quantities from everyday experience. Less than 10% of students had enough of a shot at this question to be marked reasonably. About half simply tried to guess an answer; most of the rest left the page blank. A total of four students got within a factor of 100 of our (checked) estimate, and thus received full marks.

The mean score was 0.4/6; the maximum achieved score was 6/6 and the minimum 0/6.

Question 9. Describe how an earthquake occurs. Use 20 words or less and maybe a simple diagram.

Solution and marking scheme

One mark each for:
-slipping of rock formations
-fault
-sudden
-tectonic plate
-energy release
-shaking/vibration
-relevant diagram
-etc.

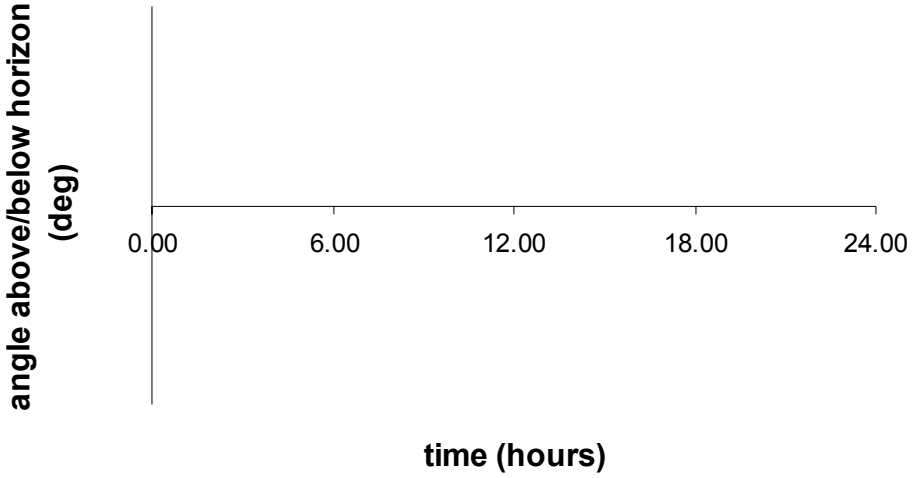
No marks off for wrong statements; zero marks for irrelevancies and vagaries

Student Responses and Remarks

Earthquakes feature regularly in the news; we wished to know if the students understood what earthquakes are, in geophysical terms. More than half of the students noted the movement of tectonic plates.

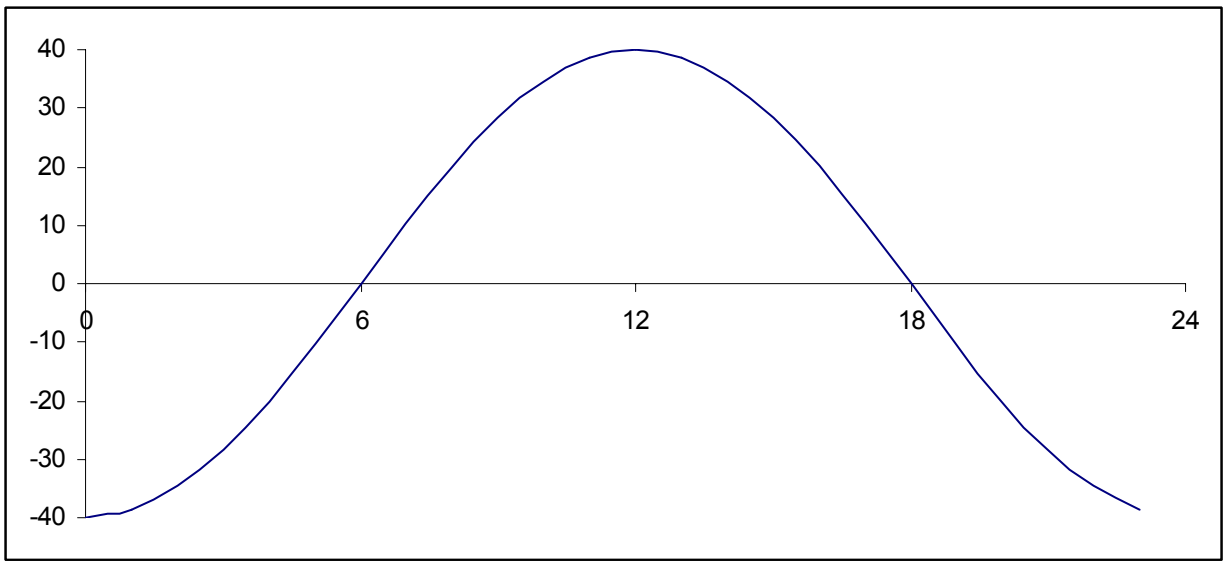
The mean score was 2.75/6; the maximum achieved score was 6/6 and the minimum 0/6.

Question 10. Sketch a graph on the axes below to show the angle of the Sun above and below the horizon over the course of 24 hours at the time of the spring equinox. Imagine you are in Winnipeg, Manitoba (latitude 50°N, longitude 97°W). Let positive values indicate angles above the horizon, and negative values indicate angles below the horizon. The times are local solar time (i.e. the Sun is highest in the sky at 12:00). Put numbers on the vertical axis.



Solution and marking scheme

Best answer:



For full marks must be symmetrical sinusoid with right maxima and minima and labelled axes

Zero if max elevation is “180deg” or 360deg”
No more than 3 marks total if max elevation is “90deg” or unmarked
No marks if line has sharp edges or discontinuities.

Student Responses and Remarks

This question is basic Earth-Sun geometry and everyday experience. The issue is whether the students who know this can translate it into graphical form, and recognize the symmetries therein. Many realized that the shape of this graph is roughly sinusoidal, but most claimed the sun to be 90deg (or 180 or 360deg) above the horizon at noon in Winnipeg on March 21st. This is also the majority response of first-year science undergraduates to this question (many of whom do not understand the significance of the word “equinox” and we presume the same problem pertains here). Although we chose Winnipeg because the numbers are singularly easy, the vast majority of Canadians live within a few degrees of the same latitude and so their solar experience will be very similar.

The mean score was 0.5/6; the maximum achieved score was 6/6 and the minimum 0/6.