UNIVERSITY OF CAMBRIDGE

NATURAL SCIENCES TRIPOS Part 1A

PHO/WP

Physiology of Organisms – Written Practical

1st June 2022 (11.00-12.30)

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*Answer **ALL 30** questions. This written practical paper (Section B of the exam) represents 25% of the total mark for Physiology of Organisms.*

You have 1.5 hours (plus any pre-agreed individual adjustment) to answer this paper.

Candidates are permitted to use an approved calculator.

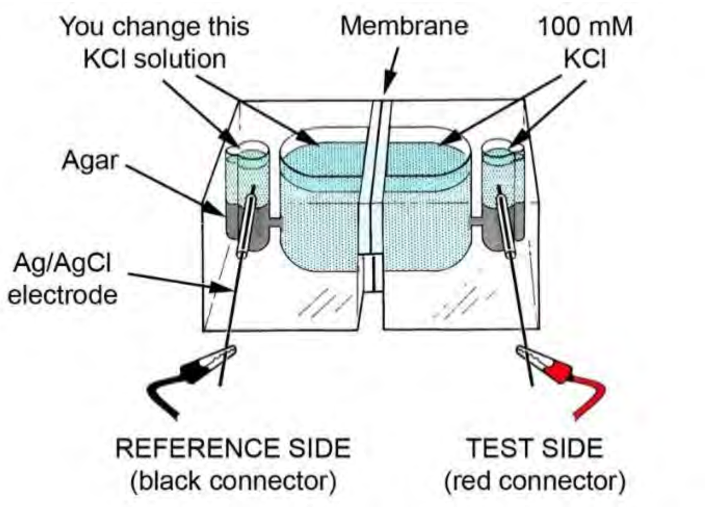
Candidates NOT using the Inspera portal: *You must submit your answers to these questions in the special answer sheet provided. Add your candidate number and attach a coversheet that also has your candidate number, plus the name of the exam (PHO/WP/B).*

You may not start to read the questions printed on the subsequent pages of this question booklet until instructed that you may do so by the Invigilator.

Stationery requirements (non-Inspera)
Rough work pad, MCQ answer sheet, coversheet, tag.

An artificial membrane was set up between a 100 mM KCl solution on one side (the test side) and a KCl solution of different concentrations on the other side (the reference side), as illustrated in Figure 1. You measured the voltage across the membrane. Questions 1 and 2 refer to Figure 1.

Figure1

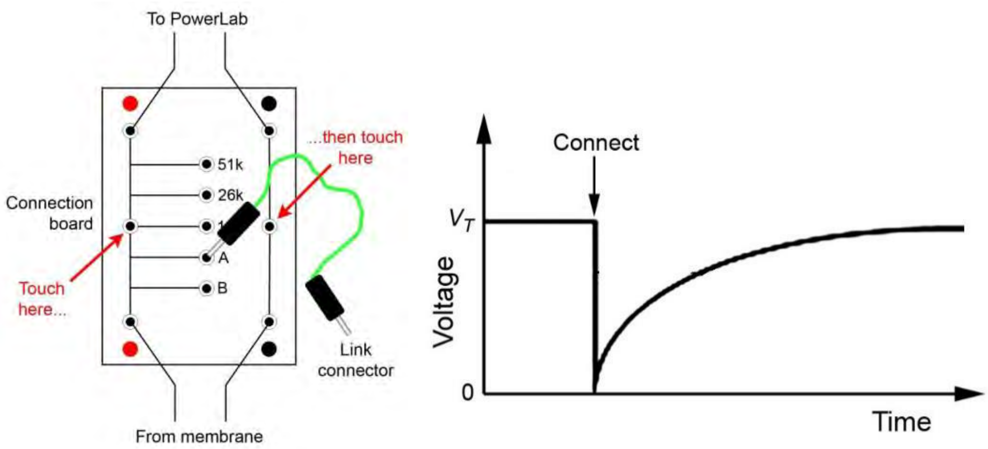


1) Which equation would most accurately predict the voltage recorded?
   A. The diffusion equation.
   B. The Nernst equation.
   C. The Goldman-Hodgkin-Katz equation.
   D. Ohm's law.
   E. The Frank-Starling law.

2) Assuming the membrane is permeable only to potassium ions, with 10 mM KCl on the reference side the expected membrane potential would be:
   A. 58 mV
   B. 10 mV
   C. 0 mV
   D. -10 mV
   E. -58 mV

Continuing the experiment, you used a circuit board (Figure 2, left) with a capacitor (A or B) to estimate the internal resistance of the membrane by measuring the time course of the voltage change recorded upon connecting the capacitor into the circuit (Figure 2, right). Question 3 refers to Figure 2.

Figure 2.

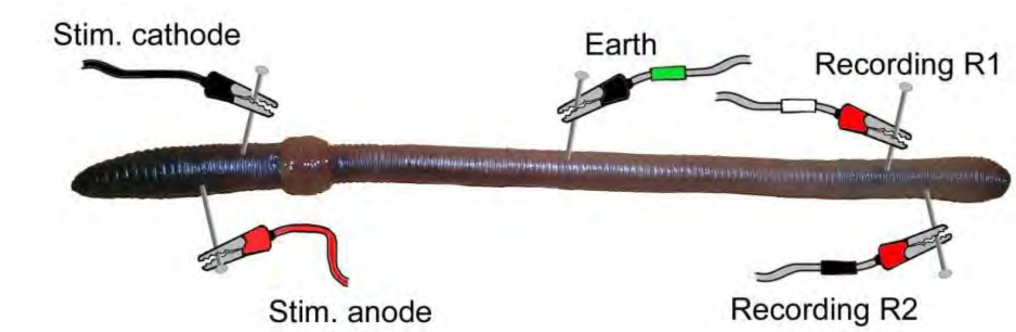


3) The time constant is given by:

A. The sum of the resistance and the capacitance.
B. The difference between the resistance and the capacitance.
C. The product of the resistance and the capacitance.
D. The square root of the ratio of the resistance to the capacitance.
E. The time constant is independent of the resistance.

A set-up to record earthworm action potentials is shown schematically in Figure 3. Questions 4, 5 and 6 refer to Figure 3.

Figure 3.



4) What is the advantage of having the stimulation cathode (stim. cathode) rather than the anode closer to the recording electrodes?

A. It reduces noise in the recording.
B. It prevents short-circuiting of the recording electrodes.
C. It allows the stimulating anode to activate the nerve fibres.
D. It prevents the anode from blocking action potential propagation to the recording site.
E. There is no advantage of having the cathode closer to the recording electrodes.

5) In the practical you measured the action potential refractory period. If the refractory period were 2 ms, what is the maximum firing frequency?

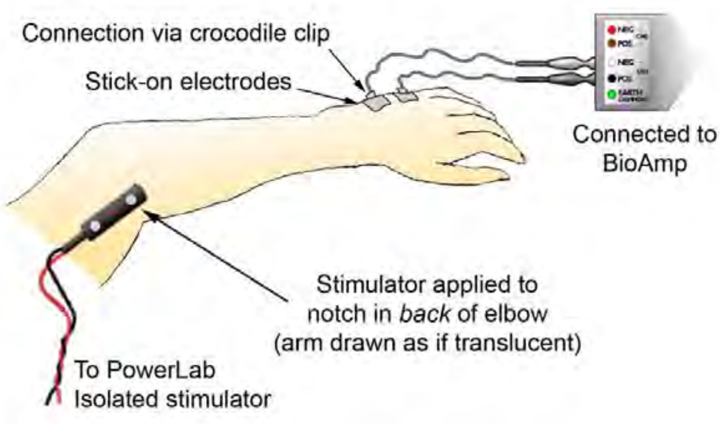
A. 2 Hz

B. 5 Hz
C. 50 Hz.
D. 500 Hz
E. 5,000 Hz

6) To estimate the action potential conduction velocity, you compared the latency from the stimulus artefact to the action potential recorded at two different distances (D1 and D2) from the stimulation cathode. If distance D1 were 6.1 cm and D2 were 9.1 cm and the latencies at D1 and D2 were measured to 3 ms and 4.5 ms, respectively, what was the conduction velocity?
A. 0.5 ms^{-1}.
B. 2 ms^{-1}.
C. 5 ms^{-1}.
D. 20 ms^{-1}.
E. 50 ms^{-1}.

In a class on muscle physiology, the EMG (electromyograph) from the abductor muscle of the little finger was recorded as shown in Figure 4. Questions 7, 8 and 9 refer to Figure 4.

Figure 4.



7) This muscle is innervated by:
A. The axillary nerve.
B. The radial nerve.
C. The median nerve.
D. The ulnar nerve.
E. None of the above.

In addition to the EMG, a force transducer was used to measure the mechanical response in the muscle to nerve stimulation.

8) Why is there a delay between the electrical and mechanical response?
A. It is because the force transducer is less sensitive.
B. It is due to the propagation of the action potential down the nerve.
C. It is due to the synaptic delay across the neuromuscular junction.

D. It is due to the delay to the initiation of the muscle action potential.
E. It is due to the excitation-contraction coupling mechanism.

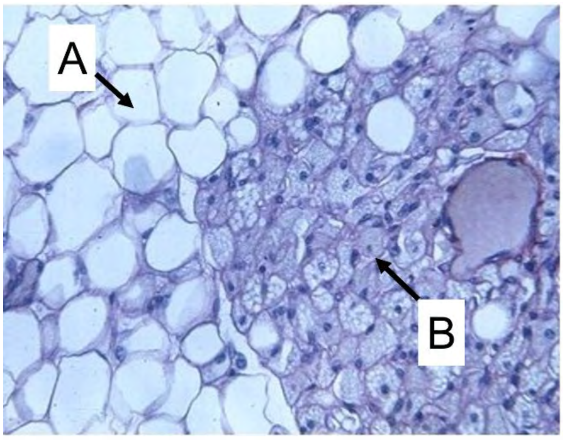
In one set of experiments a different device was used to stimulate the muscle directly.

9) What is the main mechanism for the greater force at higher stimulation frequencies?

A. Frequency facilitation at the neuromuscular junction.
B. Recruitment of additional motor units.
C. Lowered threshold for muscle fibre activation.
D. Summation of successive twitches.
E. Activation of afferent nerve fibres.

Two adjacent tissues are shown in the photomicrograph below (Figure 5). Question 10 refers to Figure 5.

Figure 5.



10) In comparison with tissue A, which of the following would you expect to be present at a higher concentration in tissue B?

A. Myoglobin.
B. Succinate dehydrogenase.
C. Haemoglobin.
D. Glucose-6-phosphate dehydrogenase.
E. Myelin.

The next two questions relate to an experiment in which students measured their own blood pressure.

11) Using an automated blood pressure cuff, the blood pressure of a healthy student at rest was measured as 124/73. Which of the following values most closely represents the mean arterial pressure of this student?

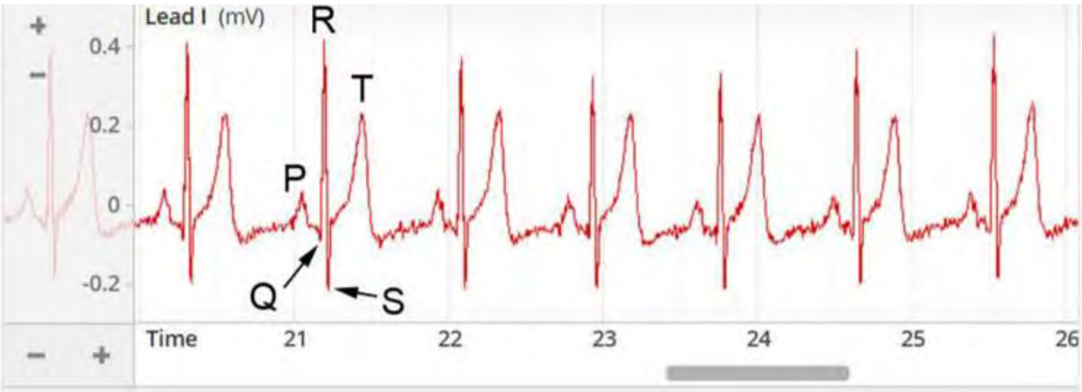
A. 111 mmHg
B. 107 mmHg
C. 99 mmHg
D. 90 mmHg
E. 85 mmHg

12) The same student then undertook a brief period of vigorous, whole-body exercise before measuring their blood pressure again. Which of the following would NOT be considered a physiologically normal response?

A. A slight fall in systolic pressure.
B. A rise in systolic pressure.
C. A slight fall in diastolic pressure.
D. A rise in diastolic pressure.
E. A rise in pulse pressure.

The trace in Figure 6 below is an electrocardiogram (ECG) recorded from a subject using Lead I electrodes. The x-axis time scale is in seconds. Question 13 refers to Figure 6.

Figure 6.

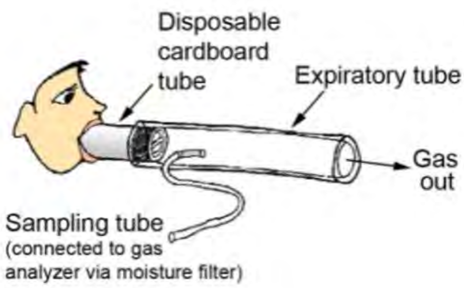


13) Which of the following statements is correct?

A. An ECG trace recorded with Lead III electrodes would be a laterally inverted form of the trace shown above.
B. The Lead III ECG would be identical in shape but differ in timings in comparison with the trace shown above.
C. Deep inspiration would be expected to alter the peak amplitude of the QRS complex in the Lead III ECG, but not the Lead I ECG.
D. The T-wave represents repolarisation of the atria.
E. The QT interval corresponds approximately to the duration of ventricular contraction.

A student used the apparatus illustrated below in Figure 7 to measure the composition of their exhaled breath. The student initially took a breath in (normal, quiet inspiration), then exhaled for as long as possible. When the readings on the gas analyser stabilised, they showed an O_2 percentage of 14.2 % and a CO_2 percentage of 5.9 %. The room temperature was 21 °C and the atmospheric pressure was 765 mmHg. Questions 14 and 15 refer to Figure 7.

Figure 7.



14) Which of the following values most closely corresponds to the partial pressure of O_2 in this subject's arterial blood?

A. 42 mmHg
B. 45 mmHg
C. 102 mmHg
D. 109 mmHg
E. 115 mmHg

15) The same subject then held their breath for 30 seconds and repeated the measurement of end expiratory gas composition. They also measured their breathing rate. Which of the following would be expected?

A. Increased P_AO_2, decreased P_ACO_2, increased breathing rate.
B. Decreased P_AO_2, increased P_ACO_2, increased breathing rate.
C. Increased P_AO_2, increased P_ACO_2, increased breathing rate.
D. Decreased P_AO_2, decreased P_ACO_2, increased breathing rate.
E. Decreased P_AO_2, decreased P_ACO_2, decreased breathing rate.

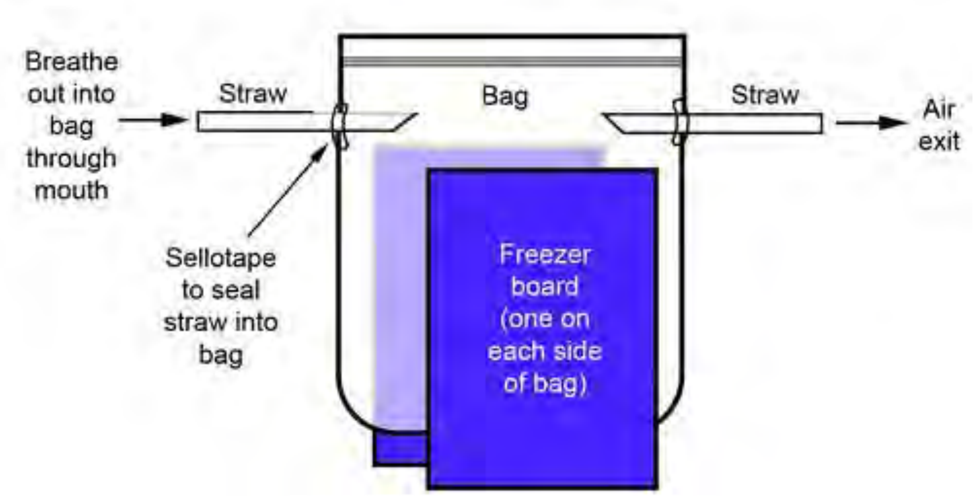
In a separate experiment, a student exercised on a cycle ergometer for 5 minutes at a work rate of 120 W. During the last minute of exercise, her pulse rate was reasonably constant at 180 bpm. By measuring her oxygen consumption, the student calculated that she had an exercise efficiency of 19 %. Use this information to answer question 16.

16) What was her total energy expenditure during the last minute of exercise?

A. 12.4 kJ min^{-1}.
B. 19.7 kJ min^{-1}.
C. 26.4 kJ min^{-1}.
D. 37.9 kJ min^{-1}.
E. 45.2 kJ min^{-1}.

In a practical class, a subject exhaled into a plastic bag, the sides of which were cooled using freezer boards, in order to collect expiratory water by condensation (apparatus shown in Figure 8). They extrapolated the amount collected in order to estimate how much would be lost over the course of a day, under resting conditions.

Figure 8.



The student was aware of limitations in this experimental design and proposed some improvements. Question 17 refers to Figure 8.

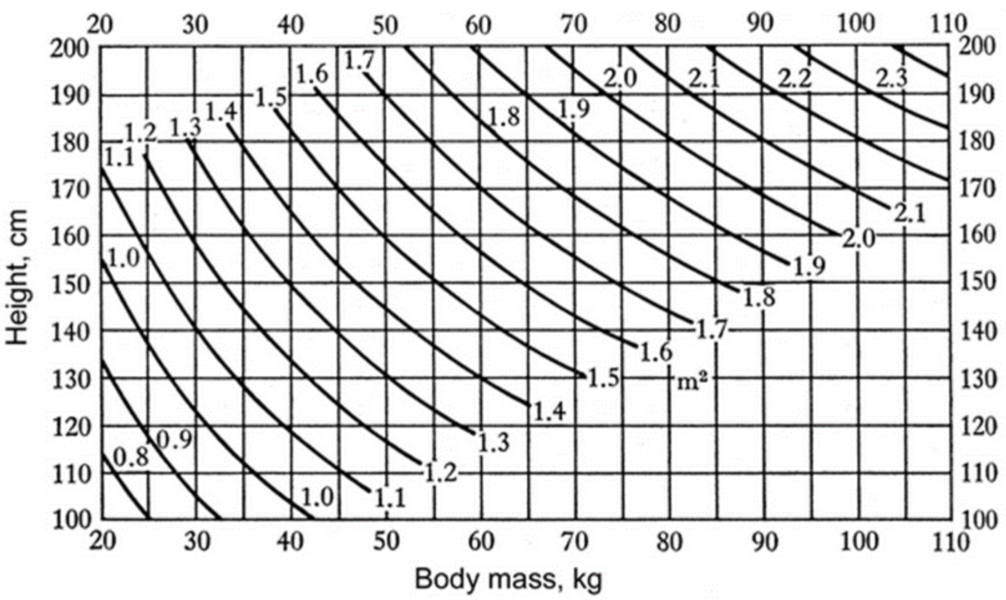
17) Which of the suggestions below would NOT make the experiment more accurate?

A. Making the inflow and outflow pipes wider.
B. Using a tightly fitted face mask so the subject could breathe through their nose as well/instead.

C. Changing the experiment to collect all the air expired in an airtight bag and cooling the bag and its contents to 4 degrees Celsius before measuring the water collected in the bag.
D. Performing the whole experiment in a colder environment.
E. Performing the whole experiment in a hotter environment.

Before designing an experiment to investigate factors which affect the rate of sweating during controlled exercise, a student generated some hypotheses. To answer this question it may help to read surface area from the nomogram below (Figure 9) and to know that for adult men, the volume of the body in litres is given by the equation: Volume (l) = 1.015 x weight (kg) – 4.937. Question 18 refers to Figure 9.

Figure 9.



18) Which of these hypotheses would be supported by a perfect experiment; *i.e.*, if all other experimental conditions were controlled for, which of these statements is TRUE?

A. A man who weighs 68 kg and is 150 cm tall would sweat less than a man who weighs 68 kg and is 190 cm tall.
B. A person wearing only a lightweight vest and shorts would sweat less than a person wearing trousers and a fleece.
C. Athletes acclimatised to exercising in a hot climate would sweat less than equally fit athletes used to exercising in a cool climate.
D. Performing the experiment in a room that is 10 degrees cooler would increase the rate of sweating.
E. The rate of sweating for a given work rate will be the same for individuals of contrasting body shape.

Body temperature is carefully regulated and subject to perturbation by both environmental (ambient temperature variation) and intrinsic (*e.g.*, thermal effect of exercise) challenges.

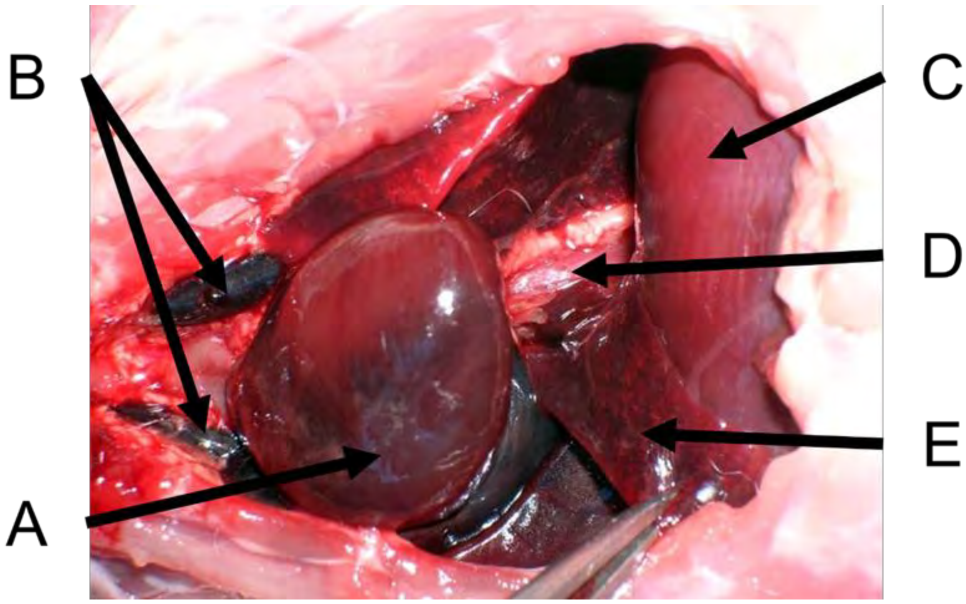
Physiologists and clinicians need to predict and measure changes in body temperature. Question 19 refers to this information.

19) Which of these statements is TRUE?

A. Infra-red tympanic thermometers are a poor indicator of core body temperature.
B. Infra-red surface imaging is a good indicator of core body temperature.
C. Oral temperature can give an artificially low indication of true body temperature during mouth breathing.
D. Normal human body temperature is 39 °C.
E. Hypothermia is a particular problem for large animals whereas small animals are more at risk of hyperthermia.

The image below (Figure 10) is of the dissected thorax of a rat. Question 20 refers to this figure.

Figure 10.



20) Which of the labels is NOT accurate?

A. Heart.
B. Superior vena cava.
C. Diaphragm.
D. Inferior vena cava.
E. Collapsed lung lobe.

A set of experiments were performed to investigate the mean power per muscle mass of the tibial extensor muscles in jumping locusts. Measurements on the isolated tibia extensor muscle showed a maximum power output of 250 Watts per kg (W/kg) muscle mass. Experimental data derived from measurements on jumps of locusts showed a mean power per muscle mass (± standard deviation) of 965 ± 472 W/kg. Question 21 refers to this information.

21) What does this tell us about how locusts power their jumps?

A. Locust muscles are less strong when measured in the isolated experimental set-up.

B. The force for the jump is not generated by muscles but by a catapult mechanism.
C. The power of isolated muscle is greater than that of the muscle in live locusts.
D. The isolated muscle is extended beyond its most powerful range.
E. The power of locust jumps is amplified by a catapult mechanism that uses stored elastic energy.

22) The rate of oxygen consumption was measured for 20 Gammarus shrimps. When plotted against body mass on log-log coordinates the data yields a regression line with a slope of approximately 0.5. Assuming the results are correct, you would conclude that:

A. Metabolic rate increases only half as fast as body mass.
B. A 10 mg shrimp has half the metabolic rate of a 40 mg shrimp.
C. Metabolic rate decreases with increasing body mass.
D. Mass-specific metabolic rate increases with increasing body mass.
E. The mass-specific metabolic rate of a 40 mg shrimp is a quarter of that of a 10 mg shrimp.

23) In a spectrophotometric assay, an absorbance (A) of 0.301 was recorded. Approximately what percentage of incoming light was absorbed by the sample?

A. 2 %
B. 10 %
C. 50 %
D. 75 %
E. 98 %

24) In a spectrophotometric assay, an absorbance reading of 0.5 was taken using a 1 cm light path cuvette. What would the absorbance reading be if a cuvette with a 1.5 cm light path cuvette were used?

A. 0
B. 0.25
C. 0.5
D. 0.75
E. 1

In an experiment to test the hypothesis that nitrate supply induces synthesis of nitrate reductase, seedlings were grown either in a growth solution with no nitrate (Set 1) or a growth solution containing 5 mM magnesium nitrate (Set 2). There is a third set of seedlings (Set 3). Use this information to answer question 25.

25) From the following options, which is the best growth solution to grow Set 3 in to test for nitrate-specific induction of nitrate reductase?

A. 5 mM magnesium nitrite.
B. 5 mM ammonium chloride.
C. 5 mM magnesium chloride.
D. 5 mM potassium nitrite.
E. 5 mM magnesium sulphate.

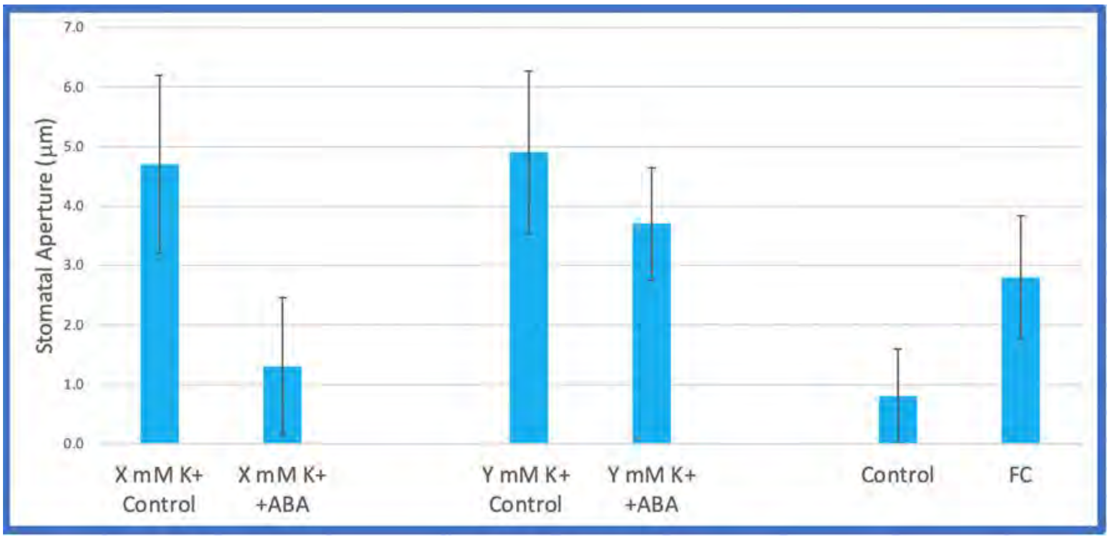
Next year's Nitrate Reductase practical will be altered so that there are 300 microlitres of radish cotyledon extract in a total of 1 ml of assay solution. The standard curve determination will also be changed so that there are 300 microlitres of nitrite standard solution in a total of 1 ml. Thus, the absorbance standard curve would continue to give nmol nitrite for enzyme rate calculations. In a test run of this modified experiment, 4 ml of extraction medium were added to 15 cotyledon pairs then 2 ml of homogenate were centrifuged. The resultant supernatant volume was estimated to be 1.05 ml. The assay was incubated for 10 minutes. A value of 10 nmol nitrite was estimated from the standard curve. Use this information to answer question 26.

26) What is the nitrate reductase activity in nmol/min/cotyledon pair?

A. 0.47.
B. 0.35.
C. 0.44.
D. 0.04.
E. 0.70.

Epidermal strips were prepared from *Commelina communis* and incubated for 30 minutes (either in light or dark) with various chemical compounds known to alter stomatal aperture. Data for a typical dataset are presented in Figure 11; mean response of stomatal aperture (n = 10 ± standard deviation) to incubation with Abscisic Acid (ABA) or Fusicoccin (FC). Consider these data to answer the questions 27 *and* 28.

Figure 11.



27) What pre-treatments would have been used to obtain the ABA treatment data from epidermal strips of *Commelina communis*?

A. Incubation in light with X = 100 mM K^+ and Y = 10 mM K^+ MES buffer.
B. Incubation in light with X = 10 mM K^+ and Y = 100 mM K^+ MES buffer.
C. Incubation in darkness with X = 100 mM K^+ and Y = 10 mM K^+ MES buffer.
D. Incubation in darkness with X = 10 mM K^+ and Y = 100 mM K^+ MES buffer.
E. Incubation in light with X = 50 mM K^+ and Y = 100 mM K^+ MES buffer.

28) Why has the stomatal aperture increased following the treatment with Fusicoccin (FC)?

A. The fungal toxin has stimulated a flavoprotein blue light photoreceptor to trigger P-type ATPase activity in the guard cell plasma membrane.

B. The fungal toxin mimics the effect of a flavoprotein blue light photoreceptor, cryptochrome, to trigger P-type ATPase activity in the guard cell plasma membrane.
C. The fungal toxin mimics the effect of a flavoprotein blue light photoreceptor, phototropin, to trigger P-type ATPase activity in the guard cell plasma membrane.
D. Chloroplasts have been activated to energise ion transport processes in guard cells.
E. The fungal toxin has increased the rate of water loss from stomata.

The equation below (Equation 1) describes the relationship between membrane potential and the differential concentration of an ion which can be maintained across a membrane by diffusion.

Equation 1.

$$E_m = \frac{58}{z} \times log_{10}\left(\frac{[X]_{out}}{[X]_{in}}\right)$$

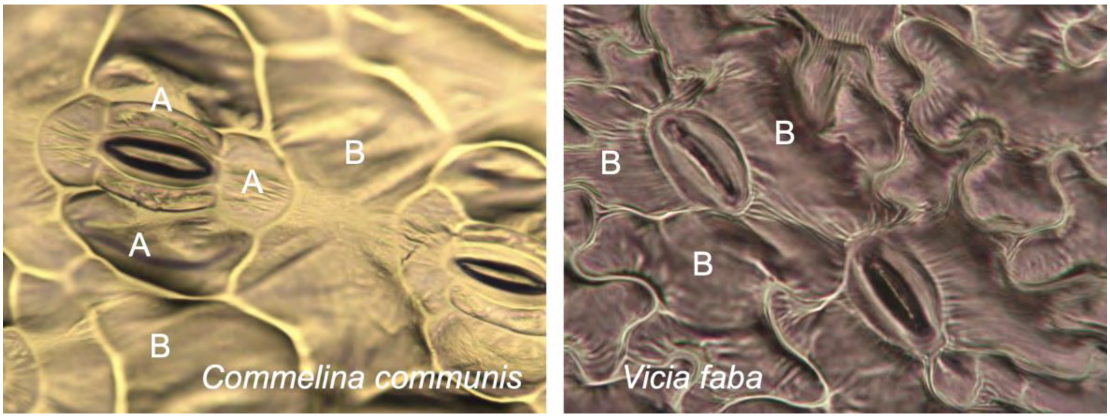
Use the equation to determine the response in question 29.

29) If the action of ABA were to lead to depolarisation of the plasma membrane potential from -100 mV to -58 mV (both inside negative), what would be the change in guard cell cytoplasmic K^+ that would be supported passively with 10 mM K^+ in an external buffer?

A. 430 mM.
B. 108 mM.
C. 530 mM.
D. 100 mM.
E. 53 mM.

Figure 12 shows images prepared from leaf surfaces using clear nail varnish. An epidermal surface impression from *Commelina communis* is shown on the left and one from *Vicia faba* is shown on the right. Both images show the cell arrangement surrounding two guard cell complexes. Question 30 refers to Figure 12.

Figure 12.



30) Which cellular interaction will have a greater impact on the sensitivity of stomatal responses in *Vicia faba*, relative to *Commelina communis*?

A. Cells labelled A provide a mechanical advantage for guard cells.
B. Cells labelled B divide to form guard cell complexes during leaf development.
C. A and B act as reservoirs for the ions needed to drive stomatal opening
D. Cells labelled B oppose guard cell turgor generation and stomatal opening.
E. In open stomata, guard cells have a higher concentration of K^+ and Cl^- than either A or B.

(END OF PAPER)