Past-paper walk-through

Cellular Energy ▪ 3.3

eXercise

Questions in this set

- 2024 Q2
- 2016 Q3
- 2015 Q2

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 2

2024 ▪ Q2

To investigate how increases in environmental temperatures affect the metabolism of certain organisms, researchers incubated liver cells from toads at different temperatures and measured two markers of metabolic activity (Table 1): the rate of oxygen consumption and the rate of ATP synthesis.

TABLE 1. RATE OF OXYGEN CONSUMPTION AND ATP SYNTHESIS AT DIFFERENT TEMPERATURES

Metabolic Marker	20°C	25°C	30°C
Rate of Oxygen Consumption (nmol / min / mg of mitochondrial protein $\pm 2\text{SE}_{\bar{x}}$)	12.8 ± 2.2	16.5 ± 2.0	22.1 ± 0.7
Rate of ATP Synthesis (nmol / min / mg of mitochondrial protein $\pm 2\text{SE}_{\bar{x}}$)	12.6 ± 1.6	16.8 ± 2.0	21.07 ± 0.8

(a) Describe the role of water in the hydrolysis of ATP.

Question 2

2024 ▪ Q2

To investigate how increases in environmental temperatures affect the metabolism of certain organisms, researchers incubated liver cells from toads at different temperatures and measured two markers of metabolic activity (Table 1): the rate of oxygen consumption and the rate of ATP synthesis.

TABLE 1. RATE OF OXYGEN CONSUMPTION AND ATP SYNTHESIS AT DIFFERENT TEMPERATURES

Metabolic Marker	20°C	25°C	30°C
Rate of Oxygen Consumption (nmol / min / mg of mitochondrial protein $\pm 2\text{SE}_{\bar{x}}$)	12.8 ± 2.2	16.5 ± 2.0	22.1 ± 0.7
Rate of ATP Synthesis (nmol / min / mg of mitochondrial protein $\pm 2\text{SE}_{\bar{x}}$)	12.6 ± 1.6	16.8 ± 2.0	21.07 ± 0.8

Question 2

(b)(i) Using the template in the space provided for your response, **construct** a bar graph that represents the data shown in Table 1. Your graph should be appropriately plotted and labeled.

(b)(ii) Based on the data provided, **determine** the temperature in °C at which the rate of oxygen consumption is different from the rate of oxygen consumption at 25°C.

Question 2

2024 ▪ Q2

To investigate how increases in environmental temperatures affect the metabolism of certain organisms, researchers incubated liver cells from toads at different temperatures and measured two markers of metabolic activity (Table 1): the rate of oxygen consumption and the rate of ATP synthesis.

TABLE 1. RATE OF OXYGEN CONSUMPTION AND ATP SYNTHESIS AT DIFFERENT TEMPERATURES

Metabolic Marker	20°C	25°C	30°C
Rate of Oxygen Consumption (nmol / min / mg of mitochondrial protein $\pm 2\text{SE}_{\bar{x}}$)	12.8 ± 2.2	16.5 ± 2.0	22.1 ± 0.7
Rate of ATP Synthesis (nmol / min / mg of mitochondrial protein $\pm 2\text{SE}_{\bar{x}}$)	12.6 ± 1.6	16.8 ± 2.0	21.07 ± 0.8

(c)(i) Based on the data in Table 1, **describe** the effect of temperature on the rate of ATP synthesis in liver cells from toads.

Question 2

(c)(ii) Based on the data in Table 1, **calculate** the average amount of oxygen consumed, in nmol, for 10 mg of mitochondrial protein after 10 minutes at 25°C.

Question 2

2024 ▪ Q2

To investigate how increases in environmental temperatures affect the metabolism of certain organisms, researchers incubated liver cells from toads at different temperatures and measured two markers of metabolic activity (Table 1): the rate of oxygen consumption and the rate of ATP synthesis.

TABLE 1. RATE OF OXYGEN CONSUMPTION AND ATP SYNTHESIS AT DIFFERENT TEMPERATURES

Metabolic Marker	20°C	25°C	30°C
Rate of Oxygen Consumption (nmol / min / mg of mitochondrial protein $\pm 2\text{SE}_{\bar{x}}$)	12.8 ± 2.2	16.5 ± 2.0	22.1 ± 0.7
Rate of ATP Synthesis (nmol / min / mg of mitochondrial protein $\pm 2\text{SE}_{\bar{x}}$)	12.6 ± 1.6	16.8 ± 2.0	21.07 ± 0.8

Question 2

(d)(i) Oligomycin is a compound that can block the channel protein function of ATP synthase. **Predict** the effects of using oligomycin on the proton gradient across the inner mitochondrial membrane.
(d)(ii) Justify your prediction.

Solution 2

(a)

Mark scheme

- Water is added to (and used to break) the bond during hydrolysis — water is added in the process of cleaving/splitting a phosphate group from ATP (water breaks down/splits ATP into ADP + inorganic phosphate).

Solution 2

(b)(i) Mark scheme

- This is a construct-a-bar-graph task; the 3 points reward: (1) the data are represented as a bar graph, (2) the graph is appropriately labeled (axes titled with quantity and units — e.g., Rate (nmol/min/mg of mitochondrial protein) vs. Metabolic Marker/Temperature — with a legend distinguishing the three temperatures 20°C/25°C/30°C or the two markers Oxygen Consumption/ATP Synthesis), and (3) the data points/bars and their error bars are plotted at the correct values from Table 1: Rate of Oxygen Consumption = 12.8 ± 2.2 (20°C), 16.5 ± 2.0 (25°C), 22.1 ± 0.7 (30°C) nmol/min/mg; Rate of ATP Synthesis = 12.6 ± 1.6 (20°C), 16.8 ± 2.0 (25°C), 21.07 ± 0.8 (30°C) nmol/min/mg. Grade a student's bar graph against these three criteria.

Solution 2

(b)(ii)

Mark scheme

- 30°C. The rate of oxygen consumption at 30°C (22.1 ± 0.7) does not overlap with the rate at 25°C (16.5 ± 2.0), while the rate at 20°C (12.8 ± 2.2) overlaps within error with the rate at 25°C, so only 30°C is clearly different.

Solution 2

(c)(i)

Mark scheme

- As temperature increases, the rate of ATP synthesis also increases — there is a positive relationship (temperature and ATP synthesis rate are directly correlated), rising from 12.6 nmol/min/mg at 20°C to 16.8 at 25°C to 21.07 at 30°C.

Solution 2

(c)(ii)

Mark scheme

- 1,650 nmol. Calculation: 16.5 nmol/min/mg (rate of O2 consumption at 25°C) $\times$ 10 mg mitochondrial protein $\times$ 10 min = 1,650 nmol.

Solution 2

(d)(i)

Mark scheme

- The proton gradient will increase/become steeper (and may eventually plateau) — equivalently, the difference in proton concentration/pH across the inner mitochondrial membrane will increase, with an increase in proton concentration (decrease in pH) in the intermembrane space relative to the matrix.

Solution 2

(d)(ii)

Mark scheme

- Without protons being able to flow back into the matrix through ATP synthase (blocked by oligomycin), more protons will accumulate in the intermembrane space/between the two mitochondrial membranes, lowering the pH there, because the electron transport chain continues pumping protons into the intermembrane space even though they can no longer flow back through ATP synthase.

Question 3

2016 ▪ Q3

[Figure 1. Percent dry weight of different plant structures during the growing season for an annual plant. Line/area graph with y-axis "Percent Dry Weight" from 0 to 100 and x-axis "Time (weeks)" labeled May, June, July, August, with germination marked by an arrow at the start of May. Seven stacked bands (bottom to top at the start, May): Roots (largest band, filling most of the graph, shrinking from 100% at germination down to about 20–30% by June and staying around 20–30% through August), Stems (a thin band above roots), Leaves (a hatched band that grows from a small sliver at germination to become the dominant band by June–July, remaining large (roughly 40–60%) through July–August), Vegetative buds (a thin black band appearing briefly around late May–June, peaking near 45–50% total height around early June then narrowing and disappearing by July), Flowers (a dark gray band appearing from July onward, growing to roughly 15–25% of the total by August),

Question 3

Receptacles (a thin white band appearing in August above flowers), and Seeds (a stippled/dotted band appearing at the very top from late July through August, reaching the 100% line). The bands together always sum to 100% at every time point.] The graph above illustrates the percent dry weight of different parts of a particular annual plant (plants that live less than one year) from early May to late August. The percent dry weight can be used to estimate the amount of energy a plant uses to produce its leaves, vegetative buds, stems, roots, and reproductive parts (seeds, receptacles, and flowers).

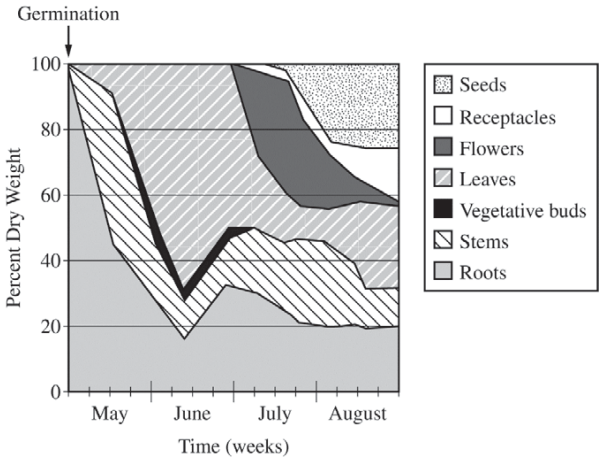
(a) Identify the direct source of the energy used for plant growth during the first week of May, and **identify** the part of the plant that grew the most during the same period.

(b) Based on the data on the graph, **estimate** the percent of the total energy that the plant has allocated to the growth of leaves on the first day of July.

Question 3

(c) Compared with perennials (plants that live more than two years), annual plants often allocate a much greater percentage of their total energy to growth of their reproductive parts in any given year. **Propose** ONE evolutionary advantage of the energy allocation strategy in annual plants compared with that in perennial plants.

Question 3


Germination
100
80
60
40
20
0
Percent Dry Weight
May
June
July
August
Time (weeks)
Seeds
Receptacles
Flowers
Leaves
Vegetative buds
Stems
Roots

Solution 3

(a)

Mark scheme

- Direct source of energy during the first week of May (1 point): the seed - specifically its stored organic nutrients/carbohydrates. Plant part that grew the most during the same period (1 point): the roots.

Solution 3

(b)

Mark scheme

- Estimate (1 point): any value between 45 and 55 percent of total energy allocated to leaf growth on the first day of July, read from the stacked-area graph.

Solution 3

(c)

Mark scheme

- Proposed evolutionary advantage (1 point, any one): allocating a much greater percentage of energy to reproductive parts increases the annual plant's chance of reproducing before it dies (since it only lives one growing season); if it did not use this strategy, it would decrease the likelihood it would ever reproduce at all, whereas a perennial can afford to invest more in vegetative growth/storage because it gets multiple years/seasons to reproduce.

Question 2

2015 ▪ Q2

[Figure 1. Glycolysis and pyruvate oxidation: Glucose (chain of 6 circles) reacts with 2 ADP + 2 Pi and 2 NAD^+ to yield 2 ATP, 2 NADH, and 2 Pyruvate (chain of 3 circles). The 2 Pyruvate are converted to 2 CO_2, 2 NADH, and 2 Acetyl-CoA (chain of 2 circles).]

[Figure 2. Krebs cycle: 2 Acetyl-CoA (2 circles) enters a cycle; 2 OAA (4 circles) combines with it going into the cycle, producing 2 TCA (6 circles) coming out. Around the cycle: inputs 2 NADH and 2 $FADH_2$ feed in; outputs are 2 CO_2, 2 NADH (first turn), 2 GTP (bottom), and 2 CO_2, 2 NADH (second turn).]

[Figure 3. Electron transport chain: A membrane diagram showing Complex I, Complex II, Complex III, and Complex IV embedded in a phospholipid bilayer. NADH and NAD^+ enter at Complex I; 2 electrons ($2e^-$) pass from Complex I and Complex II to Complex III, then to Complex IV. H^+ ions are pumped across the membrane at

Question 2

Complex I, Complex III, and Complex IV (shown by upward H^+ arrows). At Complex IV, $\frac{1}{2}O_2$ combines (with H^+) to form H_2O.]
Cellular respiration includes the metabolic pathways of glycolysis, the Krebs cycle, and the electron transport chain, as represented in the figures. In cellular respiration, carbohydrates and other metabolites are oxidized, and the resulting energy-transfer reactions support the synthesis of ATP.
(a) Using the information above, **describe** ONE contribution of each of the following in ATP synthesis.
- Catabolism of glucose in glycolysis and pyruvate oxidation - Oxidation of intermediates in the Krebs cycle - Formation of a proton gradient by the electron transport chain

Question 2

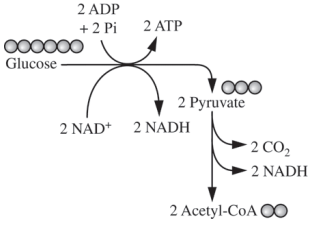


Figure 1. Glycolysis and pyruvate oxidation

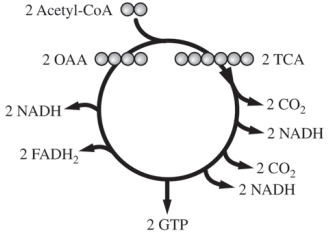
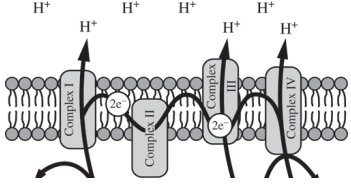
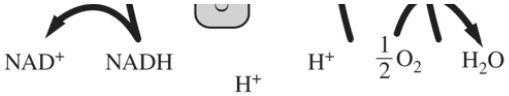


Figure 2. Krebs cycle



Question 2



Question 2

2015 ▪ Q2

[Figure 1. Glycolysis and pyruvate oxidation: Glucose (chain of 6 circles) reacts with 2 ADP + 2 Pi and 2 NAD^+ to yield 2 ATP, 2 NADH, and 2 Pyruvate (chain of 3 circles). The 2 Pyruvate are converted to 2 CO_2, 2 NADH, and 2 Acetyl-CoA (chain of 2 circles).]
[Figure 2. Krebs cycle: 2 Acetyl-CoA (2 circles) enters a cycle; 2 OAA (4 circles) combines with it going into the cycle, producing 2 TCA (6 circles) coming out. Around the cycle: inputs 2 NADH and 2 $FADH_2$ feed in; outputs are 2 CO_2, 2 NADH (first turn), 2 GTP (bottom), and 2 CO_2, 2 NADH (second turn).]
[Figure 3. Electron transport chain: A membrane diagram showing Complex I, Complex II, Complex III, and Complex IV embedded in a phospholipid bilayer. NADH and NAD^+ enter at Complex I; 2 electrons ($2e^-$) pass from Complex I and Complex II to Complex III, then to Complex IV. H^+ ions are pumped across the membrane at Complex I, Complex III, and Complex IV (shown by upward H^+ arrows). At Complex IV, $\frac{1}{2}O_2$ combines (with H^+) to form H_2O.]

Question 2

Cellular respiration includes the metabolic pathways of glycolysis, the Krebs cycle, and the electron transport chain, as represented in the figures. In cellular respiration, carbohydrates and other metabolites are oxidized, and the resulting energy-transfer reactions support the synthesis of ATP.

(b) Use each of the following observations to **justify** the claim that glycolysis first occurred in a common ancestor of all living organisms.

- Nearly all existing organisms perform glycolysis.
- Glycolysis occurs under anaerobic conditions.
- Glycolysis occurs only in the cytosol.

Question 2

2015 ▪ Q2

[Figure 1. Glycolysis and pyruvate oxidation: Glucose (chain of 6 circles) reacts with 2 ADP + 2 Pi and 2 NAD^+ to yield 2 ATP, 2 NADH, and 2 Pyruvate (chain of 3 circles). The 2 Pyruvate are converted to 2 CO_2, 2 NADH, and 2 Acetyl-CoA (chain of 2 circles).]
[Figure 2. Krebs cycle: 2 Acetyl-CoA (2 circles) enters a cycle; 2 OAA (4 circles) combines with it going into the cycle, producing 2 TCA (6 circles) coming out. Around the cycle: inputs 2 NADH and 2 $FADH_2$ feed in; outputs are 2 CO_2, 2 NADH (first turn), 2 GTP (bottom), and 2 CO_2, 2 NADH (second turn).]
[Figure 3. Electron transport chain: A membrane diagram showing Complex I, Complex II, Complex III, and Complex IV embedded in a phospholipid bilayer. NADH and NAD^+ enter at Complex I; 2 electrons ($2e^-$) pass from Complex I and Complex II to Complex III, then to Complex IV. H^+ ions are pumped across the membrane at Complex I, Complex III, and Complex IV (shown by upward H^+ arrows). At Complex IV, $\frac{1}{2}O_2$ combines (with H^+) to form H_2O.]

Question 2

Cellular respiration includes the metabolic pathways of glycolysis, the Krebs cycle, and the electron transport chain, as represented in the figures. In cellular respiration, carbohydrates and other metabolites are oxidized, and the resulting energy-transfer reactions support the synthesis of ATP.

(c) A researcher estimates that, in a certain organism, the complete metabolism of glucose produces 30 molecules of ATP for each molecule of glucose. The energy released from the total oxidation of glucose under standard conditions is 686 kcal/mol. The energy released from the hydrolysis of ATP to ADP and inorganic phosphate under standard conditions is 7.3 kcal/mol. **Calculate** the amount of energy available from the hydrolysis of 30 moles of ATP. **Calculate** the efficiency of total ATP production from 1 mole of glucose in the organism. **Describe** what happens to the excess energy that is released from the metabolism of glucose.

Question 2

2015 ▪ Q2

[Figure 1. Glycolysis and pyruvate oxidation: Glucose (chain of 6 circles) reacts with 2 ADP + 2 Pi and 2 NAD^+ to yield 2 ATP, 2 NADH, and 2 Pyruvate (chain of 3 circles). The 2 Pyruvate are converted to 2 CO_2, 2 NADH, and 2 Acetyl-CoA (chain of 2 circles).]
[Figure 2. Krebs cycle: 2 Acetyl-CoA (2 circles) enters a cycle; 2 OAA (4 circles) combines with it going into the cycle, producing 2 TCA (6 circles) coming out. Around the cycle: inputs 2 NADH and 2 $FADH_2$ feed in; outputs are 2 CO_2, 2 NADH (first turn), 2 GTP (bottom), and 2 CO_2, 2 NADH (second turn).]
[Figure 3. Electron transport chain: A membrane diagram showing Complex I, Complex II, Complex III, and Complex IV embedded in a phospholipid bilayer. NADH and NAD^+ enter at Complex I; 2 electrons ($2e^-$) pass from Complex I and Complex II to Complex III, then to Complex IV. H^+ ions are pumped across the membrane at Complex I, Complex III, and Complex IV (shown by upward H^+ arrows). At Complex IV, $\frac{1}{2}O_2$ combines (with H^+) to form H_2O.]

Question 2

Cellular respiration includes the metabolic pathways of glycolysis, the Krebs cycle, and the electron transport chain, as represented in the figures. In cellular respiration, carbohydrates and other metabolites are oxidized, and the resulting energy-transfer reactions support the synthesis of ATP.

(d) The enzymes of the Krebs cycle function in the cytosol of bacteria, but among eukaryotes the enzymes function mostly in the mitochondria. **Pose** a scientific question that connects the subcellular location of the enzymes in the Krebs cycle to the evolution of eukaryotes.

Solution 2

(a) Mark scheme

- 1 point per box, max 3 points. Catabolism of glucose in glycolysis and pyruvate oxidation: produces NADH for use in the electron transport chain (ETC), produces acetyl-CoA for entry into the Krebs cycle, and provides energy for substrate-level phosphorylation of ADP. Oxidation of intermediates in the Krebs cycle: produces NADH or FADH2 for use in the ETC, releases high-energy electrons for the ETC, provides energy to pump protons against their concentration gradient, and produces GTP via substrate-level phosphorylation of ADP. Formation of a proton gradient by the electron transport chain: the flow of protons through membrane-bound ATP synthase generates ATP, providing energy for oxidative phosphorylation of ADP.

Solution 2

(b) Mark scheme

- 1 point per box, max 3 points. Nearly all existing organisms perform glycolysis: the trait/gene/process originated early and was inherited/passed down/highly conserved because glycolysis provided a selective advantage passed on to descendants. Glycolysis occurs under anaerobic conditions: the origin of glycolysis pre-dates free atmospheric oxygen/photosynthesis. Glycolysis occurs only in the cytosol: the origin of glycolysis pre-dates cell types with membrane-bound organelles/eukaryotes/endosymbiosis. Each observation is used to justify that glycolysis is ancient enough to trace to a common ancestor of all life.

Solution 2

(c)

Mark scheme

- 1 point per box, max 3 points. Calculate available energy in ATP: 30 mol ATP $\times$ 7.3 kcal/mol = 219 kcal. Calculate efficiency: 219 kcal / 686 kcal 0.31–0.32, i.e., 31–32%. Describe fate of excess energy: the remaining energy (686 $-$ 219 467 kcal) not captured in ATP is released as heat, which increases entropy.

Solution 2

(d)

Mark scheme

- 1 point for any valid, testable scientific question connecting the subcellular location of Krebs-cycle enzymes to the evolution of eukaryotes, e.g.: 'Since the Krebs cycle occurs in the "cytoplasm" of the mitochondria (the matrix), does this suggest that mitochondria were once free-living prokaryotes (i.e., arose via endosymbiosis)?' Any comparable question linking enzyme location to eukaryotic organelle origin earns the point.