Vertex Academy

NCEA Level 3 Science workbook

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Year 13 Science: Biology investigation: temperature and Daphnia heart rate

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A Daphnia's heart beats 58 times in 15 s. What is its heart rate in beats per minute?

2. Five Daphnia at 15 °C gave 210, 224, 198, 215 and 203 beats per minute. Find the mean.

3. Using the class's means, calculate Q10 between 15 °C and 25 °C.

4. Why did the class leave each Daphnia at the test temperature for 5 minutes before counting?

5. Why is counting five different Daphnia better than counting one Daphnia five times?

6. The 30 °C group had the largest standard deviation. Give a biological reason.

7. Name one source of error that would make every reading too high, and how to reduce it.

8. Another class found Q10 = 2.1 between 10 and 20 °C. Give one reason the two classes could differ.

Fix the mistake

9. Correct this statement: "I counted the same Daphnia five times, so I have five repeats."

10. Correct this statement: "The error bars overlap, so temperature had no effect."

11. Correct this statement: "Higher temperature denatures the enzymes, so heart rate falls at 25 °C."

12. Correct this statement: "My results prove the hypothesis."

Year 13 Science: A socio-scientific issue: aerial 1080 in Aotearoa

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Why is the use of aerial 1080 a socio-scientific issue rather than a purely scientific question?

2. Explain how 1080 kills a possum.

3. Why does 1080 not build up along food chains?

4. A campaign website says a stream was poisoned after a drop but gives no test results. What two checks would you make before using the claim?

5. Give one personal action and one societal action that respond to the risk to dogs.

Fix the mistake

6. Correct this statement: "My position is that 1080 is good, because DOC says it works."

7. Correct this statement: "Hunters only oppose 1080 because they are biased."

8. Correct this statement: "1080 poisons the food chain because it builds up in animals that eat others."

9. Correct this statement: "My action is that the government should fix it."

Year 13 Science: Orientation in space: tropisms, taxes, kineses and migration

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A flatworm moves away from a bright light by steering its head from side to side. Name the response.

2. A woodlouse covers 42 cm in 60 s on dry paper. What is its speed in cm s^{-1}?

3. Why does a root bend down while a shoot bends up, if both have more auxin on the lower side?

4. Clover leaflets fold at night and open in the morning, whichever side the light comes from. Name the response.

5. What does a bird need, as well as seeing the Sun, to use a sun compass?

Exam-style question: kuaka migration

Kuaka (bar-tailed godwits) feed on worms and shellfish on New Zealand mudflats from September to March, then fly north to breed in Alaska, where the short summer brings a huge burst of insects. Young birds make their first southward flight without adults.

6. Describe the difference between migration and homing, using kuaka as an example.

7. Explain two cues kuaka could use to navigate across open ocean.

8. Discuss why migration gives kuaka a selective advantage, despite the cost of the journey.

Fix the mistake

9. Correct this statement: "Light destroys auxin on the lit side, so the shaded side grows more."

10. Correct this statement: "Woodlice move towards the damp, so it is a taxis."

11. Correct this statement: "Mimosa folding its leaves is a tropism because it responds to touch."

12. Correct this statement: "Godwits migrate so they can survive, which helps the species."

Year 13 Science: Biological rhythms: clocks, zeitgebers and photoperiodism

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. In constant darkness a hamster's activity onset moves 3 h later over 6 days. Calculate its free-running period.

2. A mouse has $\tau = 23.8$ h. In constant darkness, how much earlier will its onset be after 10 days?

3. Name the most common zeitgeber.

4. A short-day plant with a critical night length of 10 h gets 14 h of darkness, interrupted in the middle by a red flash. Will it flower?

5. Why do tidal animals need a clock period of about 12.4 h rather than 12 h?

Exam-style question: a shore crab in a tank

Shore crabs were collected from a beach and kept in a laboratory tank with no tides, in constant dim light and temperature. For the first four days they were most active at the times high tide occurred on their home beach; after that their peaks became later each day and less sharp.

6. Describe a circatidal rhythm and state what evidence shows the crabs' rhythm is endogenous.

7. Explain why the peaks drifted and became less sharp, and what would bring them back in time.

8. Discuss the selective advantage of an endogenous tidal rhythm for a crab on the shore.

Fix the mistake

9. Correct this statement: "Short-day plants flower when the days are short."

10. Correct this statement: "The rhythm stopped drifting when the lights came back, so it is exogenous."

11. Correct this statement: "Onset moved 2.5 h over days 5 to 10, so $\tau = 24 - 2.5 \div 6$."

12. Correct this statement: "Pfr builds up in the dark."

Year 13 Science: Relationships between species: competition, mutualism, exploitation

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A tūī drinks flax nectar and carries pollen on its forehead to the next flower. Name the relationship.

2. Possums eat the leaves of kāmahi trees. Name the relationship and the effect on each species.

3. Two species of Paramecium with the same diet are grown together and one dies out. Name the principle.

4. What is the difference between a fundamental and a realised niche?

5. Why is the long-tailed cuckoo's relationship with whiteheads called brood parasitism?

Exam-style question: cuckoo and warbler

The shining cuckoo spends winter in the Solomon Islands and arrives in New Zealand in September or October. The female lays one egg in each grey warbler nest she finds, and the newly hatched cuckoo chick pushes the warbler's eggs out. Grey warblers usually start their first brood in August and a second in late October.

6. Describe the relationship between the shining cuckoo and the grey warbler.

7. Explain the selective advantage of brood parasitism to the cuckoo.

8. Discuss how the timing of the warbler's breeding reduces the cost of the relationship to the warbler.

Fix the mistake

9. Correct this statement: "The bat pollinates the flower to help it."

10. Correct this statement: "Wasps and birds are in a predator–prey relationship over honeydew."

11. Correct this statement: "The realised niche is bigger than the fundamental niche."

12. Correct this statement: "Mistletoe is not a parasite because it photosynthesises."

Year 13 Science: Relationships within a species: territories, hierarchies, mating

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Tadpoles in a drying puddle all feed on the same algae until it runs out. Is this scramble or contest competition?

2. A helper raises 2 extra full siblings (r = 0.5), or could breed alone and raise 0.6 chicks. Use Hamilton's rule to decide whether helping is favoured.

3. Why do most red deer contests end in roaring and walking rather than antler fights?

4. A kekeno bull holds a beach territory where several females give birth and mate with him. Name the mating system.

5. State Hamilton's rule and say what each letter stands for.

Exam-style question: kākāpō leks

Kākāpō breed only in years when rimu trees fruit heavily. In those summers males walk to ridgetops, each clears a track-and-bowl system, and booms from its bowl for up to eight hours a night for three to four months. Females travel several kilometres to the lek, mate with one male and raise the chicks alone.

6. Describe what a lek is and identify the mating system shown.

7. Explain how booming leads to a female choosing a male.

8. Discuss why lek mating gives an advantage to the females and to the successful males, compared with males that do not display.

Fix the mistake

9. Correct this statement: "Helpers raise their siblings for the good of the species."

10. Correct this statement: "Low-ranked animals gain nothing from a hierarchy."

11. Correct this statement: "A territory is wherever an animal lives and feeds."

12. Correct this statement: "The kākāpō male booms so that it attracts a female."

Year 13 Science: Homeostasis: how animals keep their internal environment stable

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Name the control centre for body temperature and for water balance.

2. In the class's data, by how much did the core temperature fall in the 10 minutes after exercise?

3. After a big lunch, which hormone rises and which cells release it?

4. Explain how ADH reduces the volume of urine.

5. Why does a skink bask on a rock in the morning?

6. A runner loses 2 L of sweat in a hot half marathon. Explain how the body reduces further water loss.

7. Why does glucose stay high after meals in type 1 diabetes?

8. Explain why hypothermia gets worse faster once the core falls below about 32 °C.

Fix the mistake

9. Correct this statement: "When you are hot, the blood vessels move closer to the skin."

10. Correct this statement: "Glucagon is stored in the liver and turned into glucose."

11. Correct this statement: "Negative feedback keeps the temperature at exactly 37 °C."

12. Correct this statement: "Ectotherms are cold-blooded, so they cannot control their body temperature."

Year 13 Science: Mutation, gene flow, natural selection and genetic drift

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A mutation happens in a skin cell of a gecko. Can its offspring inherit the new allele?

2. A population of 50 breeding animals has p = 0.5. Find the typical chance change in p in one generation, $\sqrt{(p(1 - p) \div 2N)}$.

3. Very light and very heavy newborn lambs die more often than average ones. Which type of selection is this?

4. 100 snails are 36 AA, 48 Aa and 16 aa. A thrush eats half of the AA snails. Find f(A) among the survivors, to 2 decimal places.

5. DOC moves a few kiwi from one population to another every few years. Which process is this, and what does it do to the two gene pools?

Exam-style question: tauhou on the islands

Tauhou (silvereyes) crossed the Tasman from Australia on their own and became common in New Zealand from the 1850s. From the mainland, small groups later reached offshore islands such as the Chathams. Genetic studies find that each population founded in this chain carries fewer alleles than the one it came from, and some island birds are now larger than mainland birds.

6. Describe gene flow and genetic drift.

7. Explain why each new island population has fewer alleles than its source.

8. Explain why mutation will only slowly restore the lost diversity.

9. Discuss how drift, natural selection and the lack of gene flow could together make an island population of tauhou diverge from the mainland population.

Fix the mistake

10. Correct this statement: "The bacteria mutated to become resistant because they were exposed to the antibiotic."

11. Correct this statement: "Genetic drift means the population moved to a new place."

12. Correct this statement: "Natural selection gives organisms what they need to survive."

13. Correct this statement: "A bottleneck only lowers the number of individuals, so diversity returns when numbers recover."

Year 13 Science: Speciation and reproductive isolating mechanisms

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A zebra (2n = 44) and a horse (2n = 64) produce a zorse. How many chromosomes does the zorse have?

2. Two frog species breed in the same ponds, one in early spring and the other in summer. Name the isolating mechanism.

3. Two plant species with 2n = 14 and 2n = 18 hybridise. Give the hybrid's chromosome number, and its number after doubling.

4. Rowi and tokoeka were separated by glaciers into different forest refuges. Which mode of speciation is this?

5. A mule is healthy but cannot breed. Is this a prezygotic or postzygotic mechanism, and which one?

Exam-style question: cichlids in a crater lake

Lake Apoyo in Nicaragua is a small, isolated crater lake that formed less than about 23 000 years ago. It was colonised by the Midas cichlid, a deep-bodied fish that feeds near the lake bottom. A second species, the arrow cichlid, now also lives there: it is slender, feeds in open water, and mates only with other arrow cichlids. DNA shows the arrow cichlid evolved from Midas cichlids inside the lake.

6. Define speciation and a reproductive isolating mechanism.

7. Name two isolating mechanisms that could keep the two cichlids apart, and explain how each reduces gene flow.

8. Explain why this is sympatric rather than allopatric speciation.

9. Discuss the role of natural selection in the split, and why it happened quickly.

Fix the mistake

10. Correct this statement: "The geographic barrier is the reason they are now different species."

11. Correct this statement: "A mule is an example of hybrid inviability."

12. Correct this statement: "Geographic isolation is a postzygotic mechanism because the animals never meet."

13. Correct this statement: "A polyploid plant evolves slowly over many generations."

Year 13 Science: Patterns of evolution: divergence, convergence and radiation

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Sharks and dolphins have similar streamlined bodies. Which pattern of evolution is this?

2. Kea and kākā evolved from one ancestor into an alpine bird and a forest bird. Which pattern is this?

3. A fossil shell grows from 20.0 mm to 26.0 mm in 0.20 million years. Find the rate in mm per million years.

4. Pua o te reinga is pollinated by the short-tailed bat, which feeds on its nectar. Name the pattern.

5. Fossils show a species unchanged for 2 million years, then replaced quickly by a new form. Which model fits?

Exam-style question: the hebes

New Zealand has about a hundred species of hebe, from coastal trees to alpine cushions. DNA differences between species are small. Whipcord hebes of the high mountains have tiny scale-like leaves pressed against the stem, and look so like conifers that one species is named cupressoides, meaning cypress-like.

6. Define adaptive radiation and divergent evolution.

7. Explain two factors that allowed hebes to radiate rapidly in New Zealand.

8. Explain why the likeness of whipcord hebes to conifers is convergent evolution.

9. Discuss whether the hebe radiation better fits gradualism or punctuated equilibrium, using the evidence given.

Fix the mistake

10. Correct this statement: "Dolphins and sharks look alike, so they must share a recent common ancestor."

11. Correct this statement: "Adaptive radiation and divergent evolution are the same thing."

12. Correct this statement: "Co-evolution is when two species evolve at the same time."

13. Correct this statement: "Punctuated equilibrium means evolution happens overnight."

Year 13 Science: The evidence for evolution: fossils, anatomy, DNA and Gondwana

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A bone has 25% of its original carbon-14. Using a half-life of 5730 years, find its age.

2. Explain why carbon-14 cannot date a 2–million-year-old fossil.

3. Are a bat's wing and a human arm homologous or analogous?

4. Are a butterfly's wing and a bird's wing homologous or analogous?

5. Two species differ at 12 of 400 bases in a gene that changes by 1.0% per million years. Find the percentage difference and the time since they split.

Exam-style question: where did kiwi come from?

Zealandia began separating from Gondwana about 80 million years ago. Kiwi and moa were long thought to descend from flightless birds that were on the land when it split. A 2014 study of ancient DNA found that the closest relatives of kiwi are the extinct elephant birds of Madagascar, and that moa are most closely related to tinamous, South American birds that can fly. A small fossil kiwi relative from St Bathans in Central Otago, about 19 to 16 million years old, may have been able to fly.

6. Describe what biogeographic and molecular evidence are.

7. Explain the vicariance hypothesis for the origin of kiwi and moa.

8. Explain how the DNA results challenge that hypothesis.

9. Discuss how the fossil, molecular and biogeographic evidence together support a different origin for kiwi, and one limitation of the evidence.

Fix the mistake

10. Correct this statement: "Carbon-14 dating showed the dinosaur bones were 70 million years old."

11. Correct this statement: "After two half-lives all of the isotope has decayed."

12. Correct this statement: "Bird wings and insect wings are homologous because both are used for flying."

13. Correct this statement: "New Zealand's plants and animals are all here because they rode Zealandia away from Gondwana."

Year 13 Science: Trends in human biological evolution

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Using the table, find the percentage increase in cranial capacity from Homo habilis to Homo erectus, to the nearest whole number.

2. Where is the foramen magnum in a fully bipedal hominin?

3. Explain how the angled femur helps bipedal walking.

4. Which grip is used to hold a pen?

5. Is a chimpanzee a hominid, a hominin, or both?

Exam-style question: three skulls

Skull A has a cranial capacity of about 430 cm³, a projecting face, large canines and a U-shaped tooth row. Skull B has about 1050 cm³, a large brow ridge, a lower, longer braincase and no chin. Skull C has about 1300 cm³, a flat face, a high rounded braincase, a small brow ridge and a chin.

6. Describe two trends shown by the teeth and jaws from A to C.

7. Calculate the percentage increase in cranial capacity from B to C, to the nearest whole number.

8. Explain why the brain could only enlarge after the diet changed.

9. Discuss one advantage and one disadvantage of a larger brain for hominins, linking each to a selection pressure.

Fix the mistake

10. Correct this statement: "Humans evolved from chimpanzees."

11. Correct this statement: "The foramen magnum moved to the back of the skull in bipeds."

12. Correct this statement: "Hominins became bipedal because their brains got bigger."

13. Correct this statement: "The opposable thumb means apes cannot grip at all."

Year 13 Science: Trends in human cultural evolution

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Put these in order, oldest first: Mousterian, Oldowan, Upper Palaeolithic, Acheulean.

2. Which tool industry first shows a symmetrical shape planned before making?

3. The Acheulean began about 1.76 million years ago and the Mousterian about 250 000. About how long did the Acheulean last, in years?

4. Give the indirect evidence that clothing is at least 83 000 years old.

5. Name one biological change that cooking may have allowed.

Exam-style question: fire

Ash and burnt bone in Wonderwerk Cave suggest hominins were controlling fire by about 1 million years ago, and hearths are common at sites from about 400 000 years ago.

6. Describe two uses of fire other than cooking.

7. Explain how fire helped hominins move into colder environments.

8. Explain how cooking could have affected the biological evolution of hominins.

9. Discuss fire as an example of positive feedback between biological and cultural evolution, including one disadvantage of relying on it.

Fix the mistake

10. Correct this statement: "Cultural evolution is the same as biological evolution, just about tools."

11. Correct this statement: "Each tool industry was used only by one species."

12. Correct this statement: "Farming made people healthier straight away."

13. Correct this statement: "Fire was used to cook as soon as Homo habilis appeared."

Year 13 Science: How hominins spread across the world

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Which hominin was the first known to leave Africa, and about when?

2. From which parent do you inherit your mitochondrial DNA?

3. A haploid human genome is about 3.1 billion bases. How many bases is 4% Denisovan DNA?

4. Explain why African populations are the most genetically diverse.

5. Put these in order of first settlement: Aotearoa, Tonga, the Society Islands.

Exam-style question: our mixed ancestry

Fossils show that Homo sapiens lived in Africa from about 300 000 years ago, while Neanderthals lived in Europe and western Asia and Denisovans in Asia. Living people of European and Asian descent carry about 1 to 2% Neanderthal DNA, and Papuans carry about 4 to 6% Denisovan DNA. African populations have the greatest mtDNA diversity of any region.

6. Describe the Out of Africa (replacement) model.

7. Explain how mtDNA evidence supports an African origin for Homo sapiens.

8. Explain why Papuans carry Denisovan DNA but most Europeans do not.

9. Discuss whether the evidence supports a strict replacement model, the multiregional model, or something between.

Fix the mistake

10. Correct this statement: "Homo sapiens was the first hominin to leave Africa."

11. Correct this statement: "Mitochondrial Eve was the only woman alive at the time."

12. Correct this statement: "Mitochondrial DNA comes from both parents."

13. Correct this statement: "The Out of Africa model is wrong because people carry Neanderthal DNA."

Year 13 Science: Human manipulation of genetic transfer

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A sheep flock averages 4.0 kg of wool per sheep. Parents chosen average 5.0 kg, and $h^2 = 0.40$. Predict the offspring average.

2. EcoRI cuts this 35–base strand after the G in each GAATTC. Give the fragment lengths: CCTGA ATTCA GGCTA ATCGG CATGA ATTCA TGGCA

3. A gene from a bacterium is put into maize so the maize makes an insect toxin. Name this kind of manipulation.

4. Why does a field of cloned plants risk being wiped out by one new disease?

5. A patient's bone marrow cells are edited to treat sickle cell disease. Will the change pass to the patient's children?

Fix the mistake

6. Correct this statement: "Selective breeding creates new genes for the traits we want."

7. Correct this statement: "Gene therapy on a patient's blood cells will be passed on to their children."

8. Correct this statement: "A clone of a prize bull will look and perform exactly the same."

9. Correct this statement: "Gene editing is banned in New Zealand."

Year 13 Science: A quantitative chemistry investigation: titration analysis

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. 1.325 g of anhydrous sodium carbonate (M = 106.0 g mol^{-1}) is made up to 250.0 mL. What is its concentration?

2. 20.00 mL of that solution needs 21.60 mL of hydrochloric acid: $Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$. What is the acid's concentration?

3. Titres of 18.35, 18.70, 18.40 and 18.30 mL were recorded. What mean titre should be used?

4. A 2.00 g sample of impure ascorbic acid contains 1.76 g of $C_6H_8O_6$. What is its percentage purity?

5. A student forgot to rinse the burette with iodine solution, leaving it wet with water. Would the vitamin C results come out too high or too low?

Fix the mistake

6. Correct this statement: "I rinsed the conical flask with the juice so it would not be diluted."

7. Correct this statement: "My titres were 13.25, 13.15 and 13.80 mL, so the mean titre is 13.40 mL."

8. Correct this statement: "The 10.00 mL portion contained 2.809×10^{-4} mol, so the tablet contained 0.0494 g."

9. Correct this statement: "My results were very precise, so they must be accurate."

Year 13 Science: Spectroscopic data: identifying organic compounds

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A C_3H_8O alcohol has a broad IR dip at 3350 cm^{-1} and two peaks in its ^{13}C NMR spectrum. Name it.

2. How many peaks does pentan-3-one, $CH_3CH_2COCH_2CH_3$, give in its ^{13}C NMR spectrum?

3. A haloalkane has molecular ion peaks at m/z 78 and 80 in a 3 : 1 ratio. Which halogen is present, and what is the molecular formula?

4. An ester $C_4H_8O_2$ has its base peak at m/z 43, a CH_3CO^+ ion. Is it ethyl ethanoate or methyl propanoate?

5. Which IR evidence shows a sample is propanal and not propan-1-ol?

Fix the mistake

6. Correct this statement: "The tallest peak in the mass spectrum is the molecular ion, so M = 43."

7. Correct this statement: "Propan-2-ol has three carbons, so its ^{13}C NMR spectrum has three peaks."

8. Correct this statement: "There is a dip at 3000 cm^{-1}, so the compound has an O–H group."

9. Correct this statement: "A C=O dip at 1715 cm^{-1} means it is a ketone."

Year 13 Science: Chemical processes in the world: from natural gas to urea

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Write the balanced equation for urea hydrolysing in the soil.

2. What happens to the equilibrium yield of ammonia if the pressure is increased, and why?

3. Overall, $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$ and $N_2 + 3H_2 \rightarrow 2NH_3$. What is the minimum mass of CO_2 released in making 1.00 tonne of NH_3?

4. If ocean pH fell from 8.1 to 7.8, by what factor would $[H_3O^+]$ increase?

5. Why does the Haber process use a catalyst, when it does not change the equilibrium yield?

Fix the mistake

6. Correct this statement: "The catalyst increases the yield of ammonia."

7. Correct this statement: "Plants use a high temperature because the Haber process needs heat."

8. Correct this statement: "Urea fertiliser releases nitrate, which harms the environment."

9. Correct this statement: "The report lists five problems with fertiliser, so it is an evaluation."

Year 13 Science: Electron configuration and periodic trends

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Write the electron configuration of titanium (Z = 22).

2. Write the electron configuration of Fe^{2+} (Z = 26).

3. Which is larger, a magnesium atom or a Mg^{2+} ion?

4. Which has the higher first ionisation energy, phosphorus or sulfur?

5. Put nitrogen, oxygen and fluorine in order of increasing electronegativity.

6. Write the electron configurations of vanadium, V (Z = 23), and Ni^{2+} (Z = 28), using s, p, d notation.

7. Explain why the first ionisation energy of aluminium (578 kJ mol^{-1}) is lower than that of magnesium (738 kJ mol^{-1}).

8. The K^+ ion has a radius of 138 pm and the Cl^- ion 181 pm. Explain why K^+ is smaller, even though both ions have the same number of electrons.

9. Justify the trend in electronegativity from chlorine (3.16) to bromine (2.96) to iodine (2.66).

Fix the mistake

10. Correct this statement: "Fe^{2+} is [Ar] $3d^4\ 4s^2$, because the last electrons in are the first out."

11. Correct this statement: "Atomic radius gets bigger across a period because there are more electrons."

12. Correct this statement: "Chromium is [Ar] $3d^4\ 4s^2$, following the filling order."

13. Correct this statement: "Ionisation energy decreases down a group because there are more protons."

Year 13 Science: Shapes, polarity and intermolecular forces

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. XeF_2 has 2 bonding regions and 3 lone pairs on xenon. What is its shape?

2. What is the shape and bond angle of $SiCl_4$?

3. What is the shape of BrF_5?

4. Is PCl_5 polar or non-polar?

5. Which attractions act between CH_3Cl molecules?

6. Draw the Lewis structure of the ICl_4^- ion and name its shape.

7. Explain why the bond angle in NH_3 is about 107°, while in BF_3 it is 120°.

8. ClF_3 is polar but PCl_5 is non-polar. Explain why.

9. Ethanol, CH_3CH_2OH (46 g mol^{-1}), boils at 78 °C, methoxymethane, CH_3OCH_3 (46 g mol^{-1}), at −24 °C, and propane, C_3H_8 (44 g mol^{-1}), at −42 °C. Justify the order of boiling points.

Fix the mistake

10. Correct this statement: "XeF_4 has six regions, so its shape is octahedral."

11. Correct this statement: "When water boils, the O–H bonds break."

12. Correct this statement: "CH_3Cl contains a hydrogen atom and a chlorine atom, so it has hydrogen bonding."

13. Correct this statement: "XeF_4 has polar bonds, so it is a polar molecule."

Year 13 Science: Melting, boiling, solubility and spontaneity

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Butane (a straight chain) and 2-methylpropane (branched) are both C_4H_{10}. Which has the higher boiling point?

2. Which is more soluble in water: sodium chloride or iodine?

3. What is the sign of ΔS (system) for $H_2O(l) \rightarrow H_2O(g)$?

4. What is the sign of ΔS (system) for $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$?

5. A reaction is endothermic and its system entropy decreases. When is it spontaneous?

6. Magnesium oxide melts at 2825 °C and iodine at 114 °C. Explain the difference in terms of the particles and the attractions between them.

7. Explain why iodine dissolves in hexane but hardly at all in water.

8. Hydrogen peroxide decomposes: $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$, $\Delta rH = -196$ kJ mol^{-1}. State the sign of the entropy change of the system, and decide whether the reaction is spontaneous at all temperatures.

9. Dinitrogen tetroxide decomposes: $N_2O_4(g) \rightarrow 2NO_2(g)$, $\Delta rH = +57$ kJ mol^{-1}. Using the entropy change of the system and of the surroundings, justify why it happens on its own only at higher temperatures.

Fix the mistake

10. Correct this statement: "Iodine melts at 114 °C because its covalent I–I bonds are weak."

11. Correct this statement: "Endothermic reactions cannot be spontaneous."

12. Correct this statement: "Iodine does not dissolve in water because iodine is non-polar and repels water."

13. Correct this statement: "$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ has a positive ΔS because the SO_3 molecules are bigger."

Year 13 Science: Thermochemistry and Hess's law

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. How much energy is needed to heat 500 g of water from 18.0 °C to 100.0 °C?

2. 50.0 mL of 1.00 mol L^{-1} HCl and 50.0 mL of 1.00 mol L^{-1} NaOH are mixed and warm by 6.7 °C. Take the mass as 100 g and c = 4.18 J g^{-1} $°C^{-1}$. What is ΔrH per mole of water formed?

3. Write the equation for the standard enthalpy of formation of ethanol, $C_2H_5OH(l)$.

4. A substance has ΔfusH = 15.5 kJ mol^{-1} and ΔvapH = 41.6 kJ mol^{-1} at the same temperature. What is ΔsubH?

5. Use the ΔfH table to calculate ΔcH of methanol: $CH_3OH(l) + 1½O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$.

Exam-style question: fuels from Taranaki gas

Methanol is made from natural gas in Taranaki. Use the ΔfH table where needed.

6. Calculate ΔfH of ethyne, $C_2H_2(g)$, given ΔcH(C_2H_2) = −1300 kJ mol^{-1}, ΔcH(C) = −394 kJ mol^{-1} and ΔcH(H_2) = −286 kJ mol^{-1}.

7. Calculate ΔrH for making liquid methanol: $CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$.

8. Burning 1.20 g of methanol (M = 32.0 g mol^{-1}) heats 250 g of water from 19.5 °C to 34.0 °C. Calculate the experimental ΔcH of methanol.

9. Explain why ΔcH of methanol is less negative when the water formed is a gas, and calculate its value, using ΔvapH(H_2O) = +44.0 kJ mol^{-1}.

Fix the mistake

10. Correct this statement: "q = 0.920 × 4.18 × 21.5, using the mass of ethanol burned."

11. Correct this statement: "ΔcH = q ÷ n = +899 kJ mol^{-1}."

12. Correct this statement: "ΔrH = ΣΔfH(reactants) − ΣΔfH(products)."

13. Correct this statement: "When I reversed the methane combustion equation I kept $\Delta H = -890.3\ kJ\ mol^{-1}$."

Year 13 Science: Functional groups, naming and isomers

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Name $CH_3CH_2CH_2COCl$.

2. Name $CH_3CH(CH_3)CH_2CHO$.

3. Which of these has optical isomers: propan-2-ol, butan-2-ol, butanone or but-1-ene?

4. Which of these has geometric isomers: pent-1-ene, pent-2-ene, 2-methylbut-2-ene or pentane?

5. How many aldehydes and ketones have the formula C_4H_8O?

Exam-style question: isomers of $C_4H_8O_2$

Butanoic acid, ethyl ethanoate and 3-hydroxybutanal all have the formula $C_4H_8O_2$.

6. Name the ester $CH_3CH_2COOCH_3$, another isomer of $C_4H_8O_2$.

7. Name the branched carboxylic acid with this formula.

8. Which of the three compounds above exists as enantiomers?

9. Explain why butanoic acid boils at 164 °C and ethyl ethanoate at 77 °C.

10. Give a test that tells butanoic acid from ethyl ethanoate, with the observation.

Fix the mistake

11. Correct this statement: "But-1-ene has cis and trans isomers because it has a C=C bond."

12. Correct this statement: "$CH_3COOCH_2CH_3$ is ethanoyl ethyl, or ethyl ester ethanoate."

13. Correct this statement: "Enantiomers have different boiling points because they are different compounds."

14. Correct this statement: "The carbon in a C=O or CH_3 group can be an asymmetric carbon."

Year 13 Science: Substitution reactions: from haloalkanes to amides

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Name the organic product when 2-bromobutane is heated with KOH(aq).

2. Name the organic product when propanoic acid reacts with $SOCl_2$.

3. Name the organic product when ethanoyl chloride reacts with propan-1-ol.

4. Give the organic products when propanamide is heated with NaOH(aq).

5. What is seen when water is added to ethanoyl chloride, and why?

Exam-style question: a family of propyl compounds

1-bromopropane is heated with concentrated NH_3 to give compound A. 1-bromopropane is also heated with KOH(aq) to give compound B. Propanoic acid reacts with $SOCl_2$ to give compound C.

6. Name compound A, and say what it does to damp red litmus paper.

7. Name compound B.

8. Compound C reacts with A. Name the organic product and the type of link it contains.

9. Compound C reacts with B. Name the organic product.

10. The product from part 3 is heated under reflux with dilute HCl. Give the two organic products and explain why one of them is an ion.

Fix the mistake

11. Correct this statement: "1-bromopropane with KOH always gives propan-1-ol."

12. Correct this statement: "Hydrolysing an amide in acid gives the carboxylic acid and ammonia."

13. Correct this statement: "The ester from propanoic acid and methanol is propyl methanoate."

14. Correct this statement: "An acyl chloride dissolves in water to give a solution of the acyl chloride."

Year 13 Science: Oxidation, reduction and elimination

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Name the organic product when propan-1-ol is heated under reflux with excess acidified permanganate.

2. Which gives a silver mirror with Tollens' reagent: propanal or propanone?

3. Name the product when butanone is reduced with $NaBH_4$.

4. Name the major product when 2-bromobutane is heated with KOH in ethanol.

5. What colour change is seen when 2-methylpropan-2-ol is warmed with acidified dichromate?

Exam-style question: identifying compound P

Compound P, $C_4H_{10}O$, is an alcohol that exists as enantiomers. P is warmed with acidified dichromate to give compound Q, which gives no silver mirror with Tollens' reagent. P is also heated with concentrated H_2SO_4, giving compounds R (major) and S (minor), both of which decolourise bromine water.

6. Name compound P.

7. Name Q and give the colour change seen as it forms.

8. Explain why Q gives no silver mirror.

9. Name R and S, and explain why R is the major product.

10. Q is reduced with $NaBH_4$. Explain why the product does not rotate plane-polarised light, although P from the bottle did.

Fix the mistake

11. Correct this statement: "Heating propan-1-ol under reflux with dichromate is the way to make propanal."

12. Correct this statement: "With dichromate, the alcohol turns green."

13. Correct this statement: "Butan-2–ol gives but-2–ene only when it is dehydrated."

14. Correct this statement: "$NaBH_4$ oxidises the ketone to an alcohol."

Year 13 Science: Polyesters, polyamides, proteins and fats

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. What small molecule is lost when ethane-1,2-diol and benzene-1,4-dicarboxylic acid form PET?

2. Give the products when nylon-6,6 is heated under reflux with HCl(aq).

3. How many different dipeptides can be made from one glycine and one alanine?

4. Give the products when glyceryl tristearate (a fat) is heated with NaOH(aq).

5. Which amino acid is not chiral?

Exam-style question: PLA and nylon

PLA cups are made from lactic acid, $CH_3CH(OH)COOH$. Nylon-6,6 can be made from hexane-1,6-diamine and hexanedioyl dichloride, $ClOC(CH_2)_4COCl$.

6. Name the type of polymerisation that forms PLA, and the type of link in it.

7. Explain why lactic acid exists as enantiomers.

8. Give the organic product when PLA is heated under reflux with NaOH(aq).

9. Name the small molecule released when nylon-6,6 is made from the dichloride.

10. Explain why the dichloride route is faster than using hexanedioic acid.

Fix the mistake

11. Correct this statement: "The repeating unit of a polyester is just the ester link -COO-."

12. Correct this statement: "Glycine and alanine can only make one dipeptide."

13. Correct this statement: "Saponification of a fat gives glycerol and three fatty acids."

14. Correct this statement: "Condensation polymers form when C=C bonds break open."

Year 13 Science: Solubility and Ks

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Write the Ks expression for $PbCl_2$.

2. $Ks(BaSO_4) = 1.1 \times 10^{-10}$ at 25 °C. Calculate its solubility.

3. The solubility of CaF_2 is 2.1×10^{-4} mol L^{-1}. Calculate $Ks(CaF_2)$.

4. What happens to the solubility of AgCl when concentrated ammonia is added, and why?

5. Equal volumes of 2.0×10^{-4} mol L^{-1} $AgNO_3$ and 2.0×10^{-4} mol L^{-1} NaCl are mixed. Does AgCl precipitate? $Ks(AgCl) = 1.8 \times 10^{-10}$.

Exam-style question: zinc hydroxide

Zinc hydroxide, $Zn(OH)_2$, is a sparingly soluble white solid. $Ks(Zn(OH)_2) = 3.0 \times 10^{-17}$ at 25 °C.

6. Write the equation for the equilibrium in a saturated solution, and the Ks expression.

7. Calculate the solubility of $Zn(OH)_2$ in pure water.

8. Calculate its solubility in a solution of pH 12.00, and explain the difference.

9. When concentrated NaOH is added a little at a time, a white precipitate forms and then dissolves. Explain.

10. 10.0 mL of 2.0×10^{-4} mol L^{-1} $ZnSO_4$ is mixed with 10.0 mL of NaOH of pH 9.00. Will a precipitate form?

Fix the mistake

11. Correct this statement: "For PbI_2, $Ks = s \times 2s = 2s^2$."

12. Correct this statement: "Ag_2CrO_4 has a smaller Ks than AgCl, so it must be less soluble."

13. Correct this statement: "Adding NaCl to saturated AgCl lowers Ks."

14. Correct this statement: "Q is worked out from the concentrations of the two solutions before they are mixed."

Year 13 Science: Weak acids, bases, pH and buffers

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Write the Ka expression for HCOOH.

2. Calculate the pH of 0.050 mol L^{-1} HCOOH. Ka = 1.78×10^{-4}.

3. Calculate the pH of 0.20 mol L^{-1} NH_4Cl. Ka(NH_4^+) = 5.75×10^{-10}.

4. Which solution conducts better, 0.10 mol L^{-1} CH_3COOH or 0.10 mol L^{-1} CH_3COONa?

5. A buffer has [NH_3] = [NH_4^+] = 0.10 mol L^{-1}. What is its pH? pKa(NH_4^+) = 9.24.

Exam-style question: pool chlorine

Pools are disinfected with sodium hypochlorite, NaOCl. Hypochlorous acid, HOCl, is the better disinfectant. Ka(HOCl) = 2.95×10^{-8}, pKa = 7.53.

6. Write the Ka expression for HOCl.

7. Calculate the pH of 0.050 mol L^{-1} NaOCl.

8. List the species in 0.050 mol L^{-1} NaOCl, except water, in order of decreasing concentration.

9. A pool is kept at pH 7.50. Calculate the ratio [OCl^-] ÷ [HOCl], and say which is present in the greater amount.

10. Compare the conductivity of 0.050 mol L^{-1} NaOCl and 0.050 mol L^{-1} HOCl.

Fix the mistake

11. Correct this statement: "For 0.10 mol L^{-1} CH_3COOH, [H_3O^+] = 0.10 mol L^{-1}, so the pH is 1.00."

12. Correct this statement: "NH_4Cl is a salt, so its solution has pH 7."

13. Correct this statement: "A buffer keeps the pH exactly constant whatever is added."

14. Correct this statement: "A weak acid conducts poorly because it is dilute."

Year 13 Science: Titration curves and indicators

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. 25.0 mL of 0.120 mol L^{-1} CH_3COOH is titrated with 0.150 mol L^{-1} NaOH. What volume of NaOH reaches equivalence?

2. What is the pH at the half-equivalence point when NH_3 is titrated with HCl? $pKa(NH_4^+) = 9.24$.

3. Which indicator suits NH_3 titrated with HCl: methyl red or phenolphthalein?

4. What is the pH at the equivalence point when HCl is titrated with NaOH?

5. Name the two carbon-containing species in the buffer region of CH_3COOH titrated with NaOH.

6. 20.0 mL of 0.0850 mol L^{-1} methanoic acid, HCOOH, is titrated with 0.100 mol L^{-1} NaOH. $Ka(HCOOH) = 1.78 \times 10^{-4}$, pKa = 3.75. Calculate the volume of NaOH needed to reach equivalence.

7. Calculate the pH before any NaOH is added.

8. State the pH after 8.50 mL of NaOH has been added, and explain why.

9. Calculate the pH at the equivalence point.

10. Choose phenolphthalein or methyl orange for this titration, and justify your choice.

11. Calculate the pH after 20.0 mL of NaOH has been added.

Fix the mistake

12. Correct this statement: "The pH at the equivalence point is always 7."

13. Correct this statement: "At the half-equivalence point, pH = ½ pKa."

14. Correct this statement: "At equivalence, $[CH_3COO^-] = 0.100$ mol L^{-1}, the same as the acid."

15. Correct this statement: "Choose an indicator whose pKa equals the pKa of the acid."

Year 13 Science: Oxidation-reduction: electrode potentials and cells

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Find the oxidation number of S in $S_2O_3^{2-}$.

2. Calculate E°cell for Mg(s) | Mg^{2+}(aq) || Cu^{2+}(aq) | Cu(s).

3. Will Fe^{3+} oxidise I^-? Give E°cell.

4. In the zinc–copper cell, which electrode is the anode, and which way do electrons flow in the wire?

5. $CuSO_4$(aq) is electrolysed with graphite electrodes. What forms at each electrode?

Fix the mistake

6. Correct this statement: "For Mg + $2Ag^+$, E°cell = 2(+0.80) − (−2.37) = +3.97 V."

7. Correct this statement: "The anode is always the positive electrode."

8. Correct this statement: "Electrons flow through the salt bridge."

9. Correct this statement: "E°cell is positive, so the reaction will happen quickly."

Year 13 Science: Planning and running an independent ESS investigation

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Four repeats gave rises of 6.4, 6.6, 9.8 and 6.5 °C, and the notes say the lamp was bumped closer in the third run. Find the mean.

2. Using Aroha's line, rise = 8.4 sin θ °C, predict the rise at 50°.

3. What is the Sun's noon elevation at Invercargill (46.4° S) at an equinox?

4. Auckland is at 36.8° S. Find the noon elevations at the two solstices and how many times more energy per m² the summer Sun delivers.

5. A student increases the repeats at each angle from 3 to 5. Does this mainly improve reliability or validity?

Fix the mistake

6. Correct this statement: "Doing more repeats makes my data more valid."

7. Correct this statement: "I left out the 9.0 °C reading because it did not fit my hypothesis."

8. Correct this statement: "My conclusion is that the angle of light causes the seasons."

9. Correct this statement: "My evaluation: I could have done it more carefully."

Year 13 Science: Investigating an Earth and Space Science issue in Aotearoa

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A town's land is rising at 1.0 mm a year. Using 0.56 m of global rise from 2005 to 2100, find the local rise.

2. How many times faster was global sea level rising in 2006 to 2018 (3.7 mm a year) than in 1901 to 1971 (1.3 mm a year)?

3. A property developer's blog says sea level rise is exaggerated, with no data. How should you treat it in your report?

4. A council plans to move houses away from an eroding coast over 30 years. Which type of response is this?

5. Why can parts of Wellington face a faster local rise than the global average?

Fix the mistake

6. Correct this statement: "Melting sea ice around Antarctica is a main cause of sea level rise."

7. Correct this statement: "My personal response: I think it is a big problem and someone should fix it."

8. Correct this statement: "Every source agreed, so I only needed three websites."

9. Correct this statement: "Local sea level will rise exactly as much as the global average."

Year 13 Science: Dating geological events

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Charcoal has 25.0% of its original carbon-14. How old is it?

2. Bone has 60.0% of its original carbon-14. How old is it?

3. In a cliff, a dike cuts layers 1 to 3 and is itself offset by a fault. Which happened first, the dike or the fault?

4. A peat layer lies between the Taupō tephra and the Kaharoa tephra. What is its age range?

5. Why can a sandstone not be dated by potassium-argon on its own grains?

Fix the mistake

6. Correct this statement: "Carbon-14 dating shows the granite is 96 million years old."

7. Correct this statement: "After two half-lives all the parent isotope has gone."

8. Correct this statement: "The dike is older than the layers because it is underneath them."

9. Correct this statement: "A sandstone can be dated by measuring argon in its grains."

Year 13 Science: Ocean composition, layers and circulation

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Find the total pressure 500 m down. Use $\rho = 1025$ kg m^{-3}, $g = 9.8$ N kg^{-1} and air pressure 1.01×10^5 Pa.

2. In the Southern Hemisphere a wind blows from the south, towards the north. Which way is the net Ekman transport?

3. What happens to the salinity and density of surface water in the subtropics, where evaporation is strong?

4. Why does sea ice forming make the water beneath it denser?

5. Why is the thermocline near New Zealand stronger in summer than in winter?

Exam-style question: West Coast upwelling

Fishers on the West Coast notice that in some summers, when south-westerly winds blow for days, the sea near the shore turns cold and green and fish gather. When north-easterly winds blow, the sea stays warm and clear.

6. Describe how wind sets a surface current moving.

7. Explain how the south-westerly wind and the Coriolis effect cause upwelling along this coast.

8. Explain why upwelling makes the sea green and attracts fish.

9. Explain why north-easterly winds stop the upwelling.

Fix the mistake

10. Correct this statement: "The Coriolis effect makes currents turn right in New Zealand."

11. Correct this statement: "Ekman transport goes the same way as the wind."

12. Correct this statement: "Seawater is densest at 4 °C, so the deep ocean is at 4 °C."

13. Correct this statement: "The thermocline is the warm layer at the top."

Year 13 Science: The ocean carbon cycle and ocean acidification

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. If ocean pH fell from 8.10 to 7.80, by what factor would $[H^+]$ increase?

2. Calculate $[H^+]$ in seawater at pH 8.1.

3. Using the solubility table, how many times more CO_2 dissolves at 10 °C than at 30 °C?

4. Phytoplankton turn CO_2 into sugar, and their remains sink as marine snow. Which pump is this?

5. Why does adding CO_2 to seawater reduce the concentration of carbonate ions?

Exam-style question: carbon and pāua

The cold waters south and east of New Zealand take up large amounts of CO_2 each year. Pāua farmers worry that falling pH could affect their young pāua.

6. Describe how the physical pump moves CO_2 from the air into the deep ocean.

7. Explain how the biological pump removes carbon from surface water.

8. Using equations, explain how dissolving CO_2 lowers the pH of seawater.

9. Explain why young pāua may grow weaker shells as the ocean takes up more CO_2.

Fix the mistake

10. Correct this statement: "Ocean acidification means the sea is now an acid with a pH below 7."

11. Correct this statement: "A fall of 0.1 in pH is too small to matter."

12. Correct this statement: "Extra CO_2 gives shellfish more carbonate to build shells with."

13. Correct this statement: "Warm tropical water absorbs the most CO_2 because it has the most plankton."

Year 13 Science: Ocean heat, tides, waves and El Niño

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A swell has a period of 10 s in deep water. Find its speed.

2. Find its wavelength in deep water.

3. Find its speed in water 5.0 m deep.

4. A wave's height grows from 1.0 m to 2.0 m. By what factor does its energy increase?

5. High tide at Tauranga is at 3:40 am. About when is the next high tide?

6. During an El Niño, which way does warm surface water move, and what happens to upwelling off Peru?

Exam-style question: El Niño and a Hawke's Bay farm

NIWA has announced that an El Niño is developing. A Hawke's Bay sheep farmer wants to know what it might mean for the coming summer.

7. Describe what happens to the trade winds and the warm water of the equatorial Pacific during an El Niño.

8. Explain how these changes affect the Walker circulation and rainfall across the Pacific.

9. Explain why Hawke's Bay is more likely to be dry during an El Niño summer.

10. Explain why the farmer should treat the El Niño as a raised risk, not a certainty.

Fix the mistake

11. Correct this statement: "Waves carry water across the ocean to the beach."

12. Correct this statement: "El Niño means the trade winds get stronger."

13. Correct this statement: "Doubling a wave's height doubles its energy."

14. Correct this statement: "Spring tides happen only in spring."

Year 13 Science: Composition, layers and energy balance of the atmosphere

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Use p = 1013 e^(−h ÷ 8.0) to find the pressure at 5.5 km.

2. On a day when it is 15 °C at the ground, estimate the temperature 4.0 km up, using 6.5 °C per kilometre.

3. In which layer does temperature rise with height because ozone absorbs ultraviolet light?

4. Why is nitrogen not a greenhouse gas?

5. If Earth's albedo rose from 0.30 to 0.32, how much energy per square metre would be absorbed, taking 340 W m^{-2} arriving?

Exam-style question: summer UV in Aotearoa

Measurements at Lauder in Central Otago show that summer UV levels in New Zealand are much higher than at similar latitudes in Europe and North America.

6. Describe how ozone forms in the stratosphere and how it absorbs ultraviolet light.

7. Explain why temperature increases with height in the stratosphere.

8. Explain why New Zealand's summer UV is higher than at the same latitude in the Northern Hemisphere.

9. Explain how clouds and aerosols change the amount of UV reaching the ground.

Fix the mistake

10. Correct this statement: "The thermosphere is 1500 °C, so it would burn a spacecraft."

11. Correct this statement: "The greenhouse effect is caused by the ozone hole letting heat in."

12. Correct this statement: "Nitrogen is the main greenhouse gas because there is most of it."

13. Correct this statement: "Pressure falls by the same amount for every kilometre you climb."

Year 13 Science: Atmospheric circulation: cells, wind belts and the westerlies

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Find the Coriolis parameter f at 30° S.

2. Which wind belt is New Zealand in, and which direction does it blow from?

3. Which way does air circulate around a low in the Southern Hemisphere?

4. Air at 20 °C at sea level crosses a 1500 m range, with cloud forming from 500 m. Using 9.8 °C per km dry and 6.0 °C per km in cloud, find its temperature back at sea level on the other side.

5. Why are winds light in the doldrums?

Exam-style question: deserts and trade winds

Central Australia, at about 25° to 30° S, is one of the driest places on Earth, while northern Australia has a wet season of heavy tropical rain.

6. Describe where air rises and sinks in the Hadley cell.

7. Explain why the region near 30° S is so dry.

8. Explain why the surface trade winds in the Southern Hemisphere blow from the south-east.

9. Explain why northern New Zealand often has long settled spells in summer.

Fix the mistake

10. Correct this statement: "The westerlies blow towards the west."

11. Correct this statement: "In New Zealand air goes clockwise around a high."

12. Correct this statement: "Air sinks at 30° because it has reached the edge of the cell."

13. Correct this statement: "The nor'wester is hot because it comes from Australia."

Year 13 Science: Water, carbon, volcanoes and climate trends

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. 25 mm of rain falls on 1.0 km². How much latent heat was released when it condensed? Use $L = 2.26 \times 10^6$ J kg^{-1}.

2. Using the CO_2 table, find the average rate of rise from 2010 to 2020.

3. New Zealand's mean temperature in 2021 was 13.56 °C. How far above the 1981 to 2010 average of 12.61 °C was it?

4. Why does SO_2 that reaches the stratosphere affect climate for longer than SO_2 that stays in the troposphere?

5. Why does the CO_2 record rise and fall a little every year?

Exam-style question: the Pinatubo eruption

In June 1991, Mt Pinatubo in the Philippines erupted, sending a column of ash and gas about 35 km high and putting around 15 million tonnes of SO_2 into the stratosphere. In 1992, average global surface temperature was about 0.5 °C lower than before the eruption.

6. Describe what happened in the troposphere close to the volcano.

7. Explain how the SO_2 in the stratosphere cooled the Earth's surface.

8. Explain why the cooling was felt around the world, including in New Zealand.

9. Explain why the cooling lasted only about two years.

Fix the mistake

10. Correct this statement: "Volcanic ash in the stratosphere is what cools the climate for years."

11. Correct this statement: "Last winter was cold, so the climate is not warming."

12. Correct this statement: "Evaporation cools the air because the water takes heat from it."

13. Correct this statement: "The yearly wiggle in CO_2 is caused by people burning more fuel in winter."

Year 13 Science: Investigating an aspect of astronomy with real data

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A star of radius 7.0×10^5 km dims by 0.25% during a transit. Find the planet's radius.

2. A planet orbits a Sun-like star at 4.0 AU. What is its orbital period?

3. A star has a parallax of 0.10 arcseconds. How far away is it in parsecs and light years?

4. If a planet's radius were doubled, by what factor would its transit depth change?

5. For a report on an exoplanet's radius, which is more reliable: the NASA Exoplanet Archive or a news article, and why?

Fix the mistake

6. Correct this statement: "A 1% dip means the planet is 1% of the star's radius."

7. Correct this statement: "Kepler's third law: $T = a^3$."

8. Correct this statement: "A bigger parallax means a star is further away."

9. Correct this statement: "I used five websites, so my information is reliable."

Year 13 Science: Testing a physics theory by experiment

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Three timings of 10 oscillations are 8.42 s, 8.50 s and 8.46 s. Find T with its uncertainty.

2. Using $T = 0.846 \pm 0.004$ s, find T^2 with its absolute uncertainty.

3. Theory says $f = (1/2L)\sqrt{(F/\mu)}$, with tension F varied. What should you plot to get a straight line?

4. A graph of T^2 against m has gradient 2.47 $s^2\,kg^{-1}$. Find the spring constant k.

5. The steepest and shallowest lines on a graph have gradients 2.55 and 2.40 $s^2\,kg^{-1}$. What is the uncertainty in the gradient?

Fix the mistake

6. Correct this statement: "I timed one oscillation five times and averaged it, so my reaction time does not matter."

7. Correct this statement: "T has a 1.3% uncertainty, so T^2 has a 1.3% uncertainty too."

8. Correct this statement: "The theory has no constant term, so I forced my best-fit line through the origin."

9. Correct this statement: "My value of k is 20.0 and the other method gave 20.2, so they are different."

Year 13 Science: Physics applied to a context: fibre-optic broadband

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Find the critical angle for light going from glass (n = 1.50) into water (n = 1.33).

2. Find the speed of light in glass with n = 1.50.

3. Find the energy of a photon of wavelength 1310 nm. Use h = 6.63×10^{-34} J s.

4. Explain why a fibre's cladding must have a lower refractive index than its core.

5. How long does light take to travel 25.0 km along a fibre core with n = 1.468?

Fix the mistake

6. Correct this statement: "Total internal reflection happens when light goes from the cladding into the core."

7. Correct this statement: "The critical angle is measured from the surface of the boundary."

8. Correct this statement: "Light travels through the fibre at 3.00×10^{8} m s^{-1}."

9. Correct this statement: "My report lists refraction, photons and dispersion, so it is comprehensive."

Year 13 Science: Interference, double slits and diffraction gratings

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Two speakers in phase emit sound of wavelength 0.40 m. At point P the path difference is 1.00 m. Is P loud or quiet?

2. Light of wavelength 600 nm passes through slits 0.300 mm apart onto a screen 1.50 m away. Find the fringe spacing.

3. Find the slit spacing d of a grating with 300 lines per mm.

4. Yellow light of 589 nm shines on that grating. Find the angle of the second-order maximum.

5. What is the highest order maximum that grating gives for 589 nm light?

Exam-style question: a grating on the lab wall

Aroha shines a red laser of wavelength 635 nm through a diffraction grating with 500 lines per mm, onto a wall 1.50 m from the grating. The wall is wide enough to catch every beam.

6. Calculate the angle of the first-order maximum.

7. Calculate the distance on the wall from the central maximum to the first-order maximum.

8. Explain why the first-order maximum is bright.

9. Aroha changes to a violet laser of wavelength 405 nm. Describe and explain how the pattern changes, including how many maxima there are.

Fix the mistake

10. Correct this statement: "For a grating, $\sin\theta = x/L$, so I used $n\lambda = dx/L$ at 40°."

11. Correct this statement: "The grating has 600 lines per mm, so d = 600 mm."

12. Correct this statement: "$d \div \lambda = 3.13$, so there are 3 maxima."

13. Correct this statement: "Dark fringes are where no light reaches the screen from the slits."

Year 13 Science: Standing waves, harmonics, resonance and beats

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A string 0.500 m long carries waves at 200 m s^{-1}. Find its fundamental frequency.

2. Find the wavelength of the 4th harmonic on that string.

3. A pipe 0.250 m long is closed at one end. Using v = 340 m s^{-1}, find the next frequency it can play above its fundamental.

4. Two tuning forks of 256 Hz and 260 Hz are struck together. Find the beat frequency.

5. The tension in a string is quadrupled. What happens to its fundamental frequency?

Exam-style question: a pan flute

Wiremu makes a pan flute from plastic tubes, each closed at the bottom. Take sound's speed as 343 m s^{-1} and ignore end corrections.

6. Calculate the fundamental frequency of a tube 0.180 m long.

7. Describe the displacement pattern of the next harmonic this tube can produce and calculate its frequency.

8. He plays the tube next to a 480 Hz tuning fork. Calculate the beat frequency and explain how the beats form.

9. On a hot day the speed of sound rises to 349 m s^{-1}. Explain what happens to the tube's fundamental and to the beats with the fork.

Fix the mistake

10. Correct this statement: "Nodes on a string are one wavelength apart."

11. Correct this statement: "A closed pipe's next harmonic after f_1 is $2f_1$."

12. Correct this statement: "Two notes of 256 Hz and 260 Hz give a beat frequency of 258 Hz."

13. Correct this statement: "Doubling the tension doubles the frequency."

Year 13 Science: The Doppler effect

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A 600 Hz source moves at 20.0 m s^{-1} towards a stationary listener. Using v = 340 m s^{-1}, find the frequency heard.

2. The same source moves away from the listener at 20.0 m s^{-1}. Find the frequency heard.

3. Find the wavelength of the sound in front of the source in question 1.

4. A galaxy's 486.1 nm hydrogen line is measured at 484.2 nm. Is it approaching or moving away, and how fast?

5. A car drives in a circle around you at constant speed, sounding a 400 Hz horn. What frequency do you hear?

Exam-style question: a jet boat on the river

A jet boat on the Waikato River sounds a 750 Hz horn while travelling at 22.0 m s^{-1} straight towards Mere, who is standing on a jetty in its path. Take the speed of sound in air as 343 m s^{-1}.

6. Calculate the frequency Mere hears.

7. Explain why Mere hears a different frequency from the one the horn emits.

8. The boat swerves past the jetty and travels directly away at the same speed. Calculate the frequency she now hears.

9. An underwater microphone ahead of the boat picks up its 400 Hz engine note as 406.0 Hz while the boat approaches at 22.0 m s^{-1}. Calculate the speed of sound in the water.

Fix the mistake

10. Correct this statement: "The source is approaching, so I used v + vs on the bottom."

11. Correct this statement: "The siren itself gets higher as the ambulance speeds up."

12. Correct this statement: "The sound travels faster in front of the moving ambulance."

13. Correct this statement: "At the moment the car passes me I hear the lowest pitch."

Year 13 Science: Centre of mass and momentum in two dimensions

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A 4.0 kg mass sits at x = 0 and a 1.0 kg mass at x = 2.5 m. Where is the centre of mass?

2. A 0.0580 kg tennis ball hits a racquet at 20.0 m s^{-1} and returns straight back at 30.0 m s^{-1}. Contact lasts 4.00 ms. Find the average force on the ball.

3. A 0.400 kg ball moving east at 5.00 m s^{-1} hits a 0.600 kg ball moving north at 2.50 m s^{-1}, and they stick together. Find their velocity.

4. A 3.00 kg object at rest explodes into three 1.00 kg pieces. One goes east at 6.00 m s^{-1} and one north at 8.00 m s^{-1}. Find the velocity of the third piece.

Exam-style question: a tackle

In a rugby match, Sione (95.0 kg) runs east at 6.00 m s^{-1}. Nikau (110 kg) runs at 5.00 m s^{-1} in a direction 60.0° north of west. Nikau tackles Sione and they move off together. Ignore friction from the ground during the tackle.

5. Calculate the size of each player's momentum before the tackle.

6. Calculate the velocity of the two players just after the tackle. A vector diagram may help.

7. The tackle lasts 0.300 s. Calculate the size of the average force on Sione.

8. Explain why momentum is conserved in the tackle but kinetic energy is not.

Fix the mistake

9. Correct this statement: "Total momentum = 18 000 + 21 000 = 39 000 kg m s^{-1} for the two cars."

10. Correct this statement: "The ball hits and leaves at 12.0 m s^{-1}, so its momentum did not change and there was no impulse."

11. Correct this statement: "Momentum is conserved, so kinetic energy must be conserved as well."

12. Correct this statement: "The angle of 49.4° is just given as the answer, with no reference direction."

Year 13 Science: Circular motion and gravity

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A 0.050 kg ball on a string moves in a horizontal circle of radius 0.40 m, taking 0.50 s per revolution. Find the tension, ignoring gravity.

2. A bend of radius 120 m is banked at 12.0°. At what speed is no friction needed?

3. A roller coaster loop has radius 12.0 m at the top. What is the slowest the car can go at the top and still follow the track?

4. An 80.0 kg astronaut weighs 785 N on the Earth's surface. What is the gravitational force on her one Earth radius above the surface?

Exam-style question: an Earth observation satellite

A satellite that images New Zealand's forests orbits 700 km above the Earth's surface in a circular orbit. Earth's mass is 5.97×10^{24} kg, its radius 6.37×10^{6} m, and $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}.

5. Show that the gravitational field strength at the satellite's height is 7.97 N kg^{-1}.

6. Calculate the satellite's orbital speed.

7. Calculate its orbital period in minutes.

8. Explain why the satellite keeps a constant speed without using its engines, even though a force acts on it the whole time.

Fix the mistake

9. Correct this statement: "The free-body diagram shows weight, tension and a centripetal force."

10. Correct this statement: "For a satellite 700 km up, $F = GMm \div (7.00 \times 10^{5})^2$."

11. Correct this statement: "Astronauts in orbit are weightless because there is no gravity up there."

12. Correct this statement: "A heavier satellite must go faster to stay in the same orbit."

Year 13 Science: Rotational motion

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A wind turbine turns at 15.0 revolutions per minute. Find its angular velocity and the speed of a blade tip 40.0 m from the hub.

2. A fan spinning at 25.0 rad s^{-1} slows uniformly to rest in 10.0 s. Find its angular acceleration and how many turns it makes.

3. A net torque of 0.900 N m acts on a wheel with rotational inertia 0.0450 kg m^2. Find its angular acceleration.

4. A skater spinning at 3.00 rad s^{-1} changes her rotational inertia from 4.00 kg m^2 to 1.60 kg m^2. Find her new angular velocity and her rotational kinetic energy before and after.

Exam-style question: the potter's wheel

A potter's wheel has a rotational inertia of 0.850 kg m^2. The motor brings it from rest to 12.0 rad s^{-1} in 3.00 s with constant angular acceleration.

5. Calculate the net torque on the wheel while it speeds up.

6. Calculate how many turns the wheel makes in those 3.00 s.

7. With the motor off and the wheel spinning freely at 12.0 rad s^{-1}, the potter drops a 4.00 kg disc of clay, radius 0.120 m, centrally onto it. The clay's rotational inertia is $\frac{1}{2}mr^2$. Calculate the new angular velocity.

8. Explain why the rotational kinetic energy of the system decreases when the clay lands, even though angular momentum is conserved.

Fix the mistake

9. Correct this statement: "1200 rpm is put straight into $\omega f = \omega i + \alpha t$ as $\omega = 1200$."

10. Correct this statement: "Angular momentum is conserved, so rotational kinetic energy is conserved too."

11. Correct this statement: "The torque is F × r, using the distance to where the force acts, even when the force is at an angle."

12. Correct this statement: "The calculator is in degree mode for the trig in a rotation problem."

Year 13 Science: Simple harmonic motion

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Find the period of a simple pendulum 0.800 m long.

2. A 0.500 kg mass hangs on a spring of stiffness 20.0 N m^{-1}. Find the period.

3. An object oscillates in SHM with amplitude 5.00 cm and period 0.400 s. Find its maximum speed and maximum acceleration.

4. A 0.300 kg mass on a spring of stiffness 120 N m^{-1} oscillates with amplitude 0.0500 m. Find the total energy and the speed when y = 0.0300 m.

Exam-style question: a mass on a spring

A 0.250 kg mass hangs at rest on a spring of stiffness 40.0 N m^{-1}. It is pulled 6.00 cm below its equilibrium position and released.

5. Show that the angular frequency of the motion is 12.6 rad s^{-1}.

6. Calculate the maximum speed and the maximum acceleration of the mass.

7. Calculate the time after release when the mass first reaches 2.00 cm above equilibrium. A reference circle may help.

8. The top of the spring is then moved up and down by a hand at a frequency of 2.0 Hz. Explain, using forces and energy, why the mass oscillates with a very large amplitude.

Fix the mistake

9. Correct this statement: "$\cos^{-1}(-0.500)$ in degree mode gives 120, so t = 120 ÷ 3.927 = 30.6 s."

10. Correct this statement: "The acceleration is zero at the extremes because the object stops there."

11. Correct this statement: "Using $y = A \sin \omega t$ for a mass released from rest at the top."

12. Correct this statement: "A pendulum with a heavier bob or a bigger swing has a longer period."

Year 13 Science: Modern physics: photons, energy levels and the nucleus

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Find the energy in joules of a 450 nm photon. Use $h = 6.63 \times 10^{-34}$ J s and $c = 3.00 \times 10^{8}$ m s^{-1}.

2. Give that energy in electronvolts.

3. Those photons fall on a metal with a work function of 2.10 eV. Find the electrons' maximum kinetic energy in eV.

4. An electron in hydrogen falls from n = 4 to n = 2. Find the photon energy in eV.

5. The deuterium nucleus has a mass defect of 0.002388 u. Find its binding energy in MeV, using 1 u = 931.5 MeV.

Fix the mistake

6. Correct this statement: "Brighter light gives the photoelectrons more kinetic energy."

7. Correct this statement: "$E_k = 6.63 \times 10^{-19} - 2.28 = 6.63 \times 10^{-19}$ J."

8. Correct this statement: "The electron drops from n = 3 to n = 2, so the photon has 13.6 ÷ 3 – 13.6 ÷ 2 eV."

9. Correct this statement: "Fission releases energy because the nucleus has extra energy stored in it."

Year 13 Science: DC circuits, internal resistance and Kirchhoff's laws

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. An AA cell of EMF 1.50 V and internal resistance 0.400 Ω is connected to a 2.60 Ω resistor. Find the current and the terminal voltage.

2. A battery reads 9.00 V on open circuit and 8.40 V when it supplies 0.300 A. Find its internal resistance.

3. Currents of 2.0 A and 0.5 A flow into a junction and 1.2 A flows out along one wire. What current flows in the only other wire, and which way?

4. An e-bike battery has an EMF of 36.0 V and internal resistance 0.150 Ω. Climbing a hill, the motor draws 12.0 A. Find the terminal voltage and the power wasted in the battery.

Exam-style question: two boat batteries

On a fishing boat in the Hauraki Gulf, battery A (EMF 12.0 V, internal resistance 0.200 Ω) runs a bilge pump modelled as a 4.00 Ω resistor.

5. Calculate the current in the pump and the terminal voltage of battery A.

6. Explain why the terminal voltage is less than the EMF.

7. An older battery B (EMF 11.4 V, internal resistance 0.300 Ω) is connected in parallel with A, positive to positive. Use Kirchhoff's laws to calculate the current through each battery.

8. Explain what the sign of battery B's current tells you, and why connecting it this way wastes energy.

Fix the mistake

9. Correct this statement: "$I = \varepsilon \div R = 9.00 \div 3.50 = 2.57$ A, leaving out the battery."

10. Correct this statement: "The EMF of the battery drops when a bigger current is drawn."

11. Correct this statement: "The answer for I_2 came out negative, so I must have made a mistake."

12. Correct this statement: "In the loop equation every EMF and every IR term is added as positive."

Year 13 Science: Capacitors

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Two parallel plates, each of area 0.0100 m², are 0.200 mm apart in air. Find the capacitance.

2. Find the total capacitance of 6.0 µF and 3.0 µF in series, and in parallel.

3. How much energy does a 10 µF capacitor store at 12 V?

4. A 4.7 mF capacitor discharges through a 1.0 kΩ resistor. Find the time constant and roughly how long it takes to discharge fully.

Exam-style question: a camera flash

A camera flash stores energy in a 220 µF capacitor charged to 330 V. After each flash, it is recharged from a 330 V supply through a 1.50 kΩ resistor.

5. Calculate the charge and energy stored when the capacitor is full.

6. Calculate the time constant, the starting recharge current, and the current after one time constant.

7. Explain why the recharge current is largest at the start and falls to zero.

8. A designer suggests two 220 µF capacitors charged from the same 330 V supply. Explain, with calculations, how much energy they store connected in parallel compared with in series across 330 V.

Fix the mistake

9. Correct this statement: "6.0 µF and 3.0 µF in series make 9.0 µF."

10. Correct this statement: "$\tau = RC = 2.20 \times 470 = 1034$ s, with kΩ and µF left as they are."

11. Correct this statement: "After one time constant the capacitor is half charged."

12. Correct this statement: "When the capacitor is fully charged the current is at its maximum because the most charge is stored."

Year 13 Science: Inductors, Faraday's law and transformers

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A 0.250 T field passes at right angles through a loop of area 0.0400 m². Find the flux.

2. That flux falls to zero in 0.100 s through a 500-turn coil. Find the average induced EMF.

3. The current in a 0.200 H inductor changes at 30.0 A s^{-1}. Find the size of the back EMF.

4. A transformer has 920 primary turns on a 230 V supply. How many secondary turns give 10.0 V, and what is the primary current when the secondary supplies 2.30 A, if it is ideal?

Exam-style question: a coil on a battery

A large coil has an inductance of 2.50 H and a resistance of 5.00 Ω. It is connected through a switch to a 10.0 V battery of negligible internal resistance.

5. Calculate the final current and the time constant.

6. Calculate the rate at which the current starts to increase, and explain why the current does not jump straight to its final value.

7. Calculate the EMF across the inductor 0.300 s after the switch is closed.

8. Calculate the energy stored once the current is steady, and explain why a large voltage appears across the switch when it is opened.

Fix the mistake

9. Correct this statement: "A strong magnet sitting still inside a coil induces a large EMF."

10. Correct this statement: "When the switch closes, the current jumps to ε ÷ R and the inductor's voltage is zero."

11. Correct this statement: "A step-up transformer gives you more power, because the voltage goes up."

12. Correct this statement: "A transformer connected to a car battery will step 12 V up to 230 V."

Year 13 Science: AC circuits

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Find the peak voltage of a 12.0 V rms AC supply.

2. Find the reactance of a 0.0500 H inductor at 1000 Hz.

3. A 1.00 kΩ resistor and a 2.20 µF capacitor are in series with a 10.0 V rms, 100 Hz supply. Find X_C, the impedance and the current.

4. An AM tuner has a 250 µH coil and a 177 pF capacitor. Find its resonant frequency.

Exam-style question: a series LCR circuit

In a school lab, a 50.0 Ω resistor, a 0.150 H inductor and a 22.0 µF capacitor are connected in series to a 6.00 V rms supply whose frequency can be varied.

5. Calculate the resonant frequency of the circuit.

6. Calculate the rms current at resonance.

7. Calculate the rms current when the frequency is 50.0 Hz.

8. At 50.0 Hz, state whether the current leads or lags the supply voltage, calculate the phase angle, and explain why.

Fix the mistake

9. Correct this statement: "The supply voltage is 7.28 + 9.54 = 16.8 V."

10. Correct this statement: "Mains is 230 V, so the voltage never goes above 230 V."

11. Correct this statement: "In an inductor the current leads the voltage."

12. Correct this statement: "X_L = fL = 50.0 × 0.500 = 25.0 Ω."

Year 13 Science: A physics issue: how should New Zealand make its electricity?

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. The wind speed rises from 5 m s^{-1} to 10 m s^{-1}. By what factor does the power in the wind change?

2. Find the power in the wind through a turbine with 40.0 m blades in a 12.0 m s^{-1} wind, using $\rho = 1.20$ kg m^{-3}.

3. A line with resistance 5.00 Ω carries 400 A. Find the power lost as heat.

4. The same power is sent at twice the voltage. Find the new power lost.

5. Use the 2024 table to find hydro's share of New Zealand's electricity.

Fix the mistake

6. Correct this statement: "Wind is free, so doubling the number of turbines doubles our electricity whatever the weather."

7. Correct this statement: "My position is that renewables are good, and my action is to tell people to use less power."

8. Correct this statement: "This website says wind farms are unreliable, so they are."

9. Correct this statement: "Transmission loss is $P = V^2/R$ with the line's full voltage, so higher voltage loses more."

Answer key (for parents and tutors)

1. A Daphnia's heart beats 58 times in 15 s. What is its heart rate in beats per minute?
   58 × 4 = 232 beats per minute.
2. Five Daphnia at 15 °C gave 210, 224, 198, 215 and 203 beats per minute. Find the mean.
   (210 + 224 + 198 + 215 + 203) ÷ 5 = 1050 ÷ 5 = 210 beats per minute.
3. Using the class's means, calculate Q10 between 15 °C and 25 °C.
   Q10 = 300 ÷ 200 = 1.5.
4. Why did the class leave each Daphnia at the test temperature for 5 minutes before counting?
   So the Daphnia's body, an ectotherm, reached the water temperature before the heart rate was measured; otherwise it would still reflect the culture temperature.
5. Why is counting five different Daphnia better than counting one Daphnia five times?
   Different animals vary, so five individuals show whether the effect holds for Daphnia in general; one animal counted five times only tests the counting.
6. The 30 °C group had the largest standard deviation. Give a biological reason.
   At 30 °C Daphnia are near their upper limit, so heat stress affects individuals differently; some keep up a fast rate while others slow.
7. Name one source of error that would make every reading too high, and how to reduce it.
   The microscope lamp warming the slide during counting raises the real temperature above the set value, so the heart beats faster; switch the lamp off between counts or use a cool LED light.
8. Another class found Q10 = 2.1 between 10 and 20 °C. Give one reason the two classes could differ.
   Their Daphnia may have been a different age, size or culture, or kept at a different temperature before the test, which changes their metabolic rate.
9. Correct this statement: "I counted the same Daphnia five times, so I have five repeats."
   Those are repeat readings of one animal; independent repeats need five different Daphnia, so the result applies to Daphnia in general.
10. Correct this statement: "The error bars overlap, so temperature had no effect."
    Overlap means the difference between those two groups is uncertain, not that there is no effect; look at the whole trend and test it.
11. Correct this statement: "Higher temperature denatures the enzymes, so heart rate falls at 25 °C."
    The data show heart rate still rising at 25 °C; describe what the data show before reaching for an explanation.
12. Correct this statement: "My results prove the hypothesis."
    Results support or do not support a hypothesis; a small sample from one culture cannot prove it.

Answer key (for parents and tutors)

1. Why is the use of aerial 1080 a socio-scientific issue rather than a purely scientific question?
   Biology can describe what 1080 does, but whether to use it depends on how people weigh benefits to native birds against costs such as animal suffering, risks to dogs and cultural concerns, so people hold different views.
2. Explain how 1080 kills a possum.
   It is converted into fluorocitrate, which blocks the Krebs cycle enzyme aconitase, so aerobic respiration makes little ATP and the heart and brain fail.
3. Why does 1080 not build up along food chains?
   It is water soluble and broken down by soil and water microbes, and it is not stored in fat, so it does not accumulate in predators.
4. A campaign website says a stream was poisoned after a drop but gives no test results. What two checks would you make before using the claim?
   Validity: is there test data, is it current and peer reviewed, and does independent water monitoring agree? Bias: who runs the site and what values or interests shape what it reports?
5. Give one personal action and one societal action that respond to the risk to dogs.
   Personal: keep dogs muzzled and on a lead in drop areas until signs are removed. Societal: require warning signs and carcass monitoring until baits and carcasses have broken down.
6. Correct this statement: "My position is that 1080 is good, because DOC says it works."
   A position needs your own reasoning from the biology; quoting one organisation is not a justification.
7. Correct this statement: "Hunters only oppose 1080 because they are biased."
   Name their value and their evidence, then evaluate it; bias explains which facts they stress, not whether those facts are true.
8. Correct this statement: "1080 poisons the food chain because it builds up in animals that eat others."
   1080 is water soluble and broken down by microbes; it does not bioaccumulate, although carcasses can poison dogs that eat them.
9. Correct this statement: "My action is that the government should fix it."
   An action is specific and linked to an implication, such as funding research into species-specific toxins to answer welfare concerns.

Answer key (for parents and tutors)

1. A flatworm moves away from a bright light by steering its head from side to side. Name the response.
   Negative phototaxis, because it steers in relation to the direction of the light.
2. A woodlouse covers 42 cm in 60 s on dry paper. What is its speed in cm s^{-1}?
   42 ÷ 60 = 0.70 cm s^{-1}.
3. Why does a root bend down while a shoot bends up, if both have more auxin on the lower side?
   Root cells are much more sensitive to auxin, so the high concentration on the lower side inhibits their elongation; in shoots the same concentration speeds elongation, so the lower side grows more and the shoot bends up.
4. Clover leaflets fold at night and open in the morning, whichever side the light comes from. Name the response.
   A nastic response (nyctinasty), because the direction of movement does not depend on the direction of the stimulus.
5. What does a bird need, as well as seeing the Sun, to use a sun compass?
   An internal clock, so it can correct for the Sun moving across the sky through the day.
6. Describe the difference between migration and homing, using kuaka as an example.
   Migration is a regular seasonal journey between two areas, here between Alaska and New Zealand each year; homing is returning to a particular site, such as the same estuary or breeding ground (Achieved).
7. Explain two cues kuaka could use to navigate across open ocean.
   A time-compensated sun compass, using the internal clock to allow for the Sun's movement, and a magnetic compass reading the direction and angle of the Earth's field; the magnetic sense works under cloud, and young birds flying alone show the route depends on these inherited cues, not on following adults (Merit).
8. Discuss why migration gives kuaka a selective advantage, despite the cost of the journey.
   In Alaska long days and an insect boom give enough protein to raise chicks quickly; leaving before winter avoids freezing mudflats with no food, while New Zealand estuaries offer plentiful food in the southern summer. The journey costs a lot of fat and some birds die, but birds that migrate raise more surviving young than any that stayed in either place, so the behaviour and its inherited cues are selected for (Excellence links the cues, the timing and the food supply to breeding success).
9. Correct this statement: "Light destroys auxin on the lit side, so the shaded side grows more."
   Auxin is moved sideways to the shaded side by carrier proteins; it is redistributed, not mostly destroyed.
10. Correct this statement: "Woodlice move towards the damp, so it is a taxis."
    Woodlice do not steer towards damp air; they slow down and turn more in it, which is a kinesis.
11. Correct this statement: "Mimosa folding its leaves is a tropism because it responds to touch."
    It is a nastic response: fast, reversible, caused by turgor change, and its direction does not depend on where it was touched.
12. Correct this statement: "Godwits migrate so they can survive, which helps the species."
    Selection acts on individuals: birds that migrate leave more surviving offspring, so the migratory behaviour spreads.

Answer key (for parents and tutors)

1. In constant darkness a hamster's activity onset moves 3 h later over 6 days. Calculate its free-running period.
   3 h ÷ 6 = 0.5 h later per day, so τ = 24 + 0.5 = 24.5 h.
2. A mouse has τ = 23.8 h. In constant darkness, how much earlier will its onset be after 10 days?
   24 − 23.8 = 0.2 h per day; 0.2 × 10 = 2 h earlier.
3. Name the most common zeitgeber.
   Light.
4. A short-day plant with a critical night length of 10 h gets 14 h of darkness, interrupted in the middle by a red flash. Will it flower?
   No: the red flash converts Pr back to Pfr, so the plant reads two nights of 7 h, each shorter than the 10 h critical night length, and Pfr stays high.
5. Why do tidal animals need a clock period of about 12.4 h rather than 12 h?
   High tide comes about 50 minutes later each day, because tides follow the Moon, so the cycle is about 12 h 25 min.
6. Describe a circatidal rhythm and state what evidence shows the crabs' rhythm is endogenous.
   A circatidal rhythm repeats about every 12.4 h, matching the tides. The rhythm continued in a tank with no tides, so it is generated by an internal clock, not by the water itself (Achieved).
7. Explain why the peaks drifted and became less sharp, and what would bring them back in time.
   Without tides as a zeitgeber the clock free-runs with its own period, slightly different from the real tidal cycle, so each peak falls a little later; different crabs drift at different rates, so the group's peaks spread out. Returning them to the shore, where wave action and immersion reset the clock, would entrain them again (Merit).
8. Discuss the selective advantage of an endogenous tidal rhythm for a crab on the shore.
   The clock lets a crab become active and leave shelter just before the tide covers it, when it can feed and is hidden from shorebirds, and retreat before the tide leaves, when it would dry out and be exposed to birds and gulls. Crabs that anticipate the tide feed longer and are eaten less than ones that only react to it, so they survive and breed more, and entrainment keeps that timing right as the tide shifts each day (Excellence links clock, zeitgeber and niche).
9. Correct this statement: "Short-day plants flower when the days are short."
   They respond to an uninterrupted night longer than the critical length; a short flash of light at night stops them flowering even in short days.
10. Correct this statement: "The rhythm stopped drifting when the lights came back, so it is exogenous."
    Drift in constant conditions shows it is endogenous; the lights coming back simply entrain it again.
11. Correct this statement: "Onset moved 2.5 h over days 5 to 10, so τ = 24 − 2.5 ÷ 6."
    Days 5 to 10 is 5 intervals, not 6 rows, so the shift is 0.5 h per day and τ = 23.5 h.
12. Correct this statement: "Pfr builds up in the dark."
    Pfr is made in red light; in the dark it slowly reverts to Pr, which is how the plant measures the night.

Answer key (for parents and tutors)

1. A tūī drinks flax nectar and carries pollen on its forehead to the next flower. Name the relationship.
   Mutualism: the tūī gains nectar, the flax is pollinated.

2. Possums eat the leaves of kāmahi trees. Name the relationship and the effect on each species.
   Herbivory, a form of exploitation: the possum gains food (+), the kāmahi loses leaves and photosynthetic area (−).

3. Two species of Paramecium with the same diet are grown together and one dies out. Name the principle.
   The competitive exclusion principle: two species with identical niches cannot coexist.

4. What is the difference between a fundamental and a realised niche?
   The fundamental niche is the full range a species could occupy with no competitors; the realised niche is the smaller part it occupies when competitors are present.

5. Why is the long-tailed cuckoo's relationship with whiteheads called brood parasitism?
   The cuckoo lays its egg in the whitehead's nest and the whiteheads raise the cuckoo chick, losing their own brood: the cuckoo exploits their parental care.

6. Describe the relationship between the shining cuckoo and the grey warbler.
   Brood parasitism, a form of exploitation: the cuckoo gains (+) because the warbler raises its chick, and the warbler loses (−) its own eggs and the energy spent feeding the cuckoo (Achieved).

7. Explain the selective advantage of brood parasitism to the cuckoo.
   The cuckoo spends no energy building nests, incubating or feeding chicks, so a female can lay many eggs, one per nest, spreading the risk across many hosts; more of her energy goes into eggs, so she leaves more offspring than a bird raising one brood itself. Ejecting the warbler eggs means the chick gets all the food (Merit).

8. Discuss how the timing of the warbler's breeding reduces the cost of the relationship to the warbler.
   The warbler's first brood begins in August, before cuckoos arrive, so it is raised unparasitised and the pair still produces young that season; only the second brood is at risk. Warblers that breed early leave more surviving offspring than late breeders, so early breeding is selected for, which limits the cuckoo's impact and lets both species persist; the cuckoo in turn depends on the warbler's second brood being timed with its own arrival (Excellence links both species' timing to reproductive success).

9. Correct this statement: "The bat pollinates the flower to help it."
   The bat is feeding for its own benefit; pollination is a side effect that selection has favoured in the plant.

10. Correct this statement: "Wasps and birds are in a predator–prey relationship over honeydew."
    They compete: both use the same limited honeydew, and each lowers the amount left for the other.

11. Correct this statement: "The realised niche is bigger than the fundamental niche."
    The realised niche is the part of the fundamental niche a species keeps once competitors and predators are present, so it is never larger.

12. Correct this statement: "Mistletoe is not a parasite because it photosynthesises."
    It is a hemiparasite: it makes its own sugars but takes water and minerals from the host's xylem.

Answer key (for parents and tutors)

1. Tadpoles in a drying puddle all feed on the same algae until it runs out. Is this scramble or contest competition?
   Scramble competition: no tadpole defends the algae; all share it until it runs out.
2. A helper raises 2 extra full siblings (r = 0.5), or could breed alone and raise 0.6 chicks. Use Hamilton's rule to decide whether helping is favoured.
   r × B = 0.5 × 2 = 1.0, and C = 0.6 chicks given up; 1.0 > 0.6, so helping is favoured.
3. Why do most red deer contests end in roaring and walking rather than antler fights?
   Ritualised displays let stags judge each other's strength, so the weaker one withdraws without injury and the winner avoids wounds; fights happen only between closely matched stags.
4. A kekeno bull holds a beach territory where several females give birth and mate with him. Name the mating system.
   Polygyny.
5. State Hamilton's rule and say what each letter stands for.
   r × B > C: r is the relatedness to the individuals helped, B the extra offspring they raise because of the help, and C the offspring the helper gives up.
6. Describe what a lek is and identify the mating system shown.
   A lek is a gathering of males at display sites, where they compete only by display and females come to choose; males give no parental care, and a few males mate with many females, so it is a form of polygyny (Achieved).
7. Explain how booming leads to a female choosing a male.
   The bowl acts as an amplifier, so the low-frequency boom carries several kilometres at night and leads females to the lek; females compare booming males and choose one, probably on how long and how strongly he can keep booming (Merit).
8. Discuss why lek mating gives an advantage to the females and to the successful males, compared with males that do not display.
   Booming for months costs a male a lot of body fat, so only males in the best condition can keep it up: it is an honest signal. Females raise chicks alone in a rare mast year, so choosing a high-quality male gives chicks better genes for survival; they gain nothing else from males. Successful males father many chicks while weak or silent males father none, so alleles for strong booming spread despite the cost (Excellence links signal, choice and reproductive success).
9. Correct this statement: "Helpers raise their siblings for the good of the species."
   Kin selection works at the level of alleles: helping relatives passes on copies of the helper's own alleles.
10. Correct this statement: "Low-ranked animals gain nothing from a hierarchy."
    They avoid costly fights, keep group protection from predators and may rise in rank and breed later.
11. Correct this statement: "A territory is wherever an animal lives and feeds."
    That is a home range; a territory is the part that is actively defended against others of the same species.
12. Correct this statement: "The kākāpō male booms so that it attracts a female."
    Say why that works: booming is costly, so only fit males can keep it up, and females choosing them get chicks with better survival.

Answer key (for parents and tutors)

1. Name the control centre for body temperature and for water balance.
   The hypothalamus controls both.
2. In the class's data, by how much did the core temperature fall in the 10 minutes after exercise?
   37.9 − 37.1 = 0.8 °C.
3. After a big lunch, which hormone rises and which cells release it?
   Insulin, released by beta cells in the islets of the pancreas.
4. Explain how ADH reduces the volume of urine.
   ADH makes collecting duct cells insert aquaporins into their membranes, so more water moves back into the blood by osmosis and less leaves as urine.
5. Why does a skink bask on a rock in the morning?
   It is an ectotherm, so it absorbs heat from the sun and the warm rock to raise its body temperature until its enzymes and muscles work well enough to hunt.
6. A runner loses 2 L of sweat in a hot half marathon. Explain how the body reduces further water loss.
   Sweating makes the blood more concentrated; osmoreceptors in the hypothalamus detect this and the posterior pituitary releases more ADH, so the collecting ducts reabsorb more water and less urine is made, and thirst makes the runner drink.
7. Why does glucose stay high after meals in type 1 diabetes?
   The beta cells have been destroyed by the immune system, so no insulin is released; muscle and fat cells do not move GLUT4 into their membranes and the liver does not store glycogen, so glucose stays in the blood.
8. Explain why hypothermia gets worse faster once the core falls below about 32 °C.
   The hypothalamus and muscles are too cold to keep up shivering, and enzymes slow, so less heat is made; as heat production falls the core cools faster, a positive feedback that negative feedback can no longer correct.
9. Correct this statement: "When you are hot, the blood vessels move closer to the skin."
   Blood vessels do not move; the skin arterioles widen, so more blood flows through the surface capillaries.
10. Correct this statement: "Glucagon is stored in the liver and turned into glucose."
    Glycogen is the stored carbohydrate; glucagon is the hormone that tells the liver to break glycogen down.
11. Correct this statement: "Negative feedback keeps the temperature at exactly 37 °C."
    It keeps the temperature within a narrow range, with small swings above and below the set point.
12. Correct this statement: "Ectotherms are cold-blooded, so they cannot control their body temperature."
    Ectotherms regulate mostly by behaviour, such as basking or sheltering, and can hold a fairly steady temperature.

Answer key (for parents and tutors)

1. A mutation happens in a skin cell of a gecko. Can its offspring inherit the new allele?
   No: a skin cell is a body (somatic) cell, and only mutations in the germ line reach eggs or sperm.
2. A population of 50 breeding animals has p = 0.5. Find the typical chance change in p in one generation, $\sqrt{(p(1-p) \div 2N)}$.
   $\sqrt{(0.5 \times 0.5 \div 100)} = \sqrt{0.0025} = 0.05$.
3. Very light and very heavy newborn lambs die more often than average ones. Which type of selection is this?
   Stabilising selection: both extremes are selected against, so the average is kept and variation narrows.
4. 100 snails are 36 AA, 48 Aa and 16 aa. A thrush eats half of the AA snails. Find f(A) among the survivors, to 2 decimal places.
   18 AA, 48 Aa and 16 aa survive = 82 snails = 164 alleles; A = (2 × 18) + 48 = 84, so f(A) = 84 ÷ 164 = 0.51 (it was 0.60).
5. DOC moves a few kiwi from one population to another every few years. Which process is this, and what does it do to the two gene pools?
   Gene flow: it adds alleles to each population and makes the two gene pools more alike.
6. Describe gene flow and genetic drift.
   Gene flow is the movement of alleles between populations when individuals migrate and breed; genetic drift is a random change in allele frequencies from one generation to the next (Achieved).
7. Explain why each new island population has fewer alleles than its source.
   Each island was colonised by a few founders, who carried only a sample of their source population's alleles, with rare alleles likely to be missed; this founder effect is a form of drift, and further drift in the small new population loses more alleles (Merit).
8. Explain why mutation will only slowly restore the lost diversity.
   Mutation is the only source of brand new alleles, but the rate per gene is very low, most new mutations are harmful or neutral, and a new allele starts as a single copy that drift can easily lose in a small population (Merit).
9. Discuss how drift, natural selection and the lack of gene flow could together make an island population of tauhou diverge from the mainland population.
   The founder effect gave each island a different, smaller gene pool by chance, and drift kept changing it strongly while numbers were low. The sea limits gene flow, so mainland alleles rarely arrive to undo those differences. Island conditions, such as different food and fewer predators, select for different phenotypes, so larger body size may have been favoured by directional selection. Selection and drift both change the isolated island gene pool and gene flow does not oppose them, so the island population diverges further each generation, which could in time lead to reproductive isolation (Excellence: links all three processes to the evidence).
10. Correct this statement: "The bacteria mutated to become resistant because they were exposed to the antibiotic."
    Resistance alleles arose by random mutation before exposure; the antibiotic only selected for them by killing the rest.
11. Correct this statement: "Genetic drift means the population moved to a new place."
    Drift is a random change in allele frequencies; moving between populations is gene flow.
12. Correct this statement: "Natural selection gives organisms what they need to survive."
    Selection can only act on variation already present; it changes how common existing alleles are.
13. Correct this statement: "A bottleneck only lowers the number of individuals, so diversity returns when numbers recover."
    Lost alleles do not come back when numbers rise; only new mutation or gene flow can restore diversity, and both are slow.

Answer key (for parents and tutors)

1. A zebra (2n = 44) and a horse (2n = 64) produce a zorse. How many chromosomes does the zorse have?
   22 + 32 = 54 chromosomes.
2. Two frog species breed in the same ponds, one in early spring and the other in summer. Name the isolating mechanism.
   Temporal isolation, a prezygotic mechanism: they breed at different times, so never mate.
3. Two plant species with 2n = 14 and 2n = 18 hybridise. Give the hybrid's chromosome number, and its number after doubling.
   7 + 9 = 16 chromosomes, sterile because none pair; doubled, 2 × 16 = 32, and fertile.
4. Rowi and tokoeka were separated by glaciers into different forest refuges. Which mode of speciation is this?
   Allopatric speciation: a geographic barrier stopped gene flow between the populations.
5. A mule is healthy but cannot breed. Is this a prezygotic or postzygotic mechanism, and which one?
   Postzygotic: hybrid sterility.
6. Define speciation and a reproductive isolating mechanism.
   Speciation is the process by which one species splits into two or more; a reproductive isolating mechanism is anything that prevents members of two groups producing fertile offspring together (Achieved).
7. Name two isolating mechanisms that could keep the two cichlids apart, and explain how each reduces gene flow.
   Habitat isolation: arrow cichlids live and feed in open water and Midas cichlids near the bottom, so they rarely meet to breed. Behavioural isolation: each fish chooses mates of its own body shape, so even when they meet they do not mate. Both are prezygotic and cut the flow of alleles between the groups (Merit for each linked to the fish).
8. Explain why this is sympatric rather than allopatric speciation.
   The lake is small and isolated with no barrier inside it, both species live in the same water, and DNA shows the arrow cichlid came from Midas cichlids within the lake, so the split happened without geographic separation (Merit).
9. Discuss the role of natural selection in the split, and why it happened quickly.
   The open-water niche was empty, so disruptive selection favoured both slender fish that fed well in open water and deep-bodied fish that fed well on the bottom, while intermediate fish did poorly at both. Because fish also chose mates like themselves, the two forms stopped exchanging alleles, so selection could push each gene pool further apart instead of being undone by interbreeding. Strong selection on an empty niche, plus assortative mating, explains how speciation happened in under about 23 000 years, a short time in evolutionary terms (Excellence).
10. Correct this statement: "The geographic barrier is the reason they are now different species."
    The barrier only stops gene flow; different mutations, selection and drift then change the gene pools until isolating mechanisms form.
11. Correct this statement: "A mule is an example of hybrid inviability."
    A mule lives a normal life, so it shows hybrid sterility; inviability means the hybrid dies or is too weak to reach adulthood.
12. Correct this statement: "Geographic isolation is a postzygotic mechanism because the animals never meet."
    Anything that stops mating or fertilisation is prezygotic; postzygotic means a zygote forms and the hybrid then fails.
13. Correct this statement: "A polyploid plant evolves slowly over many generations."
    Polyploidy isolates a plant from its parents in one generation, which is why it is called instant or sudden speciation.

Answer key (for parents and tutors)

1. Sharks and dolphins have similar streamlined bodies. Which pattern of evolution is this?
   Convergent evolution: they are unrelated, and similar selection pressures produced analogous features.
2. Kea and kākā evolved from one ancestor into an alpine bird and a forest bird. Which pattern is this?
   Divergent evolution: one ancestor, different selection pressures in different habitats.
3. A fossil shell grows from 20.0 mm to 26.0 mm in 0.20 million years. Find the rate in mm per million years.
   6.0 ÷ 0.20 = 30 mm per million years.
4. Pua o te reinga is pollinated by the short-tailed bat, which feeds on its nectar. Name the pattern.
   Co-evolution (a mutualism): each species is a selection pressure on the other.
5. Fossils show a species unchanged for 2 million years, then replaced quickly by a new form. Which model fits?
   Punctuated equilibrium: long stasis, then a short burst of change.
6. Define adaptive radiation and divergent evolution.
   Adaptive radiation is the rapid divergent evolution of one ancestral species into many species, each adapted to a different niche; divergent evolution is the process by which related populations become more different as they adapt to different selection pressures (Achieved).
7. Explain two factors that allowed hebes to radiate rapidly in New Zealand.
   The rise of the Southern Alps created many new habitats (alpine scree, bog, cushion field) with few competing plants, so open niches were available; populations on separate ranges and in different habitats had little gene flow, so selection and drift could split them into species quickly (Merit for each factor explained).
8. Explain why the likeness of whipcord hebes to conifers is convergent evolution.
   Whipcord hebes and conifers are not closely related, but both face cold, dry, windy conditions, so selection favoured small, tough leaves with little surface for water loss in both; the scale leaves are analogous structures built independently (Merit, Excellence if linked to the selection pressure and contrasted with homologous features).
9. Discuss whether the hebe radiation better fits gradualism or punctuated equilibrium, using the evidence given.
   Small DNA differences show the species split recently and fast, so the radiation looks like a burst of speciation rather than slow, steady change, which fits punctuated equilibrium at the scale of the group. However, there is little fossil evidence for hebes, so the pattern cannot be checked layer by layer, and each species could still have changed gradually after it formed; the DNA evidence supports a rapid burst but cannot fully rule out gradual change (Excellence: evaluates the evidence for both models).
10. Correct this statement: "Dolphins and sharks look alike, so they must share a recent common ancestor."
    Their similarity is convergent: they are distantly related, and similar selection pressures in water produced analogous body shapes.
11. Correct this statement: "Adaptive radiation and divergent evolution are the same thing."
    Adaptive radiation is divergent evolution that happens rapidly, from one ancestor into many species filling many niches.
12. Correct this statement: "Co-evolution is when two species evolve at the same time."
    Co-evolution needs each species to be a selection pressure on the other, so changes in one cause changes in the other.
13. Correct this statement: "Punctuated equilibrium means evolution happens overnight."
    The bursts take thousands of years, which is quick only compared with the millions of years of stasis around them.

Answer key (for parents and tutors)

1. A bone has 25% of its original carbon-14. Using a half-life of 5730 years, find its age.
   100% → 50% → 25% is 2 half-lives, so 2 × 5730 = 11 460 years.
2. Explain why carbon-14 cannot date a 2-million-year-old fossil.
   After about 50 000 years (nearly 9 half-lives) too little carbon-14 is left to measure, so far older fossils need a long half-life isotope such as potassium-40 in nearby volcanic rock.
3. Are a bat's wing and a human arm homologous or analogous?
   Homologous: the same bones from a common ancestor, used for different jobs.
4. Are a butterfly's wing and a bird's wing homologous or analogous?
   Analogous: same job, different structure and origin.
5. Two species differ at 12 of 400 bases in a gene that changes by 1.0% per million years. Find the percentage difference and the time since they split.
   12 ÷ 400 × 100 = 3.0%, so 3.0 ÷ 1.0 = 3.0 million years.
6. Describe what biogeographic and molecular evidence are.
   Biogeographic evidence is the pattern of where species and their relatives are found; molecular evidence compares DNA or protein sequences, where fewer differences mean a more recent common ancestor (Achieved).
7. Explain the vicariance hypothesis for the origin of kiwi and moa.
   Vicariance says the ancestors of kiwi and moa lived on Gondwana and were carried away on Zealandia when it split off about 80 million years ago, so they evolved in isolation from flightless ancestors already there (Merit).
8. Explain how the DNA results challenge that hypothesis.
   If kiwi had been isolated since the split, their closest relatives should be other ancient New Zealand birds such as moa, but DNA shows kiwi are closest to elephant birds of Madagascar and moa to flying tinamous, so the two New Zealand groups are not each other's relatives, and flightlessness evolved separately in each (Merit).
9. Discuss how the fossil, molecular and biogeographic evidence together support a different origin for kiwi, and one limitation of the evidence.
   Madagascar separated from the other land long before kiwi and elephant birds split, so the shared ancestor most likely flew to both places, and flight was lost later in each by convergent evolution; the St Bathans fossil fits this, as a kiwi relative that may still have flown. The tinamou link shows the same for moa ancestors. Together the evidence supports dispersal by flight after Zealandia separated, rather than vicariance. A limitation is that molecular clock dates depend on assumed rates and fossil calibration, and the St Bathans fossil is known from only a few bones, so whether it flew is uncertain (Excellence: links all three lines of evidence and evaluates them).
10. Correct this statement: "Carbon-14 dating showed the dinosaur bones were 70 million years old."
    Carbon-14 is gone after about 50 000 years; old fossils are dated from volcanic layers using isotopes such as potassium-40.
11. Correct this statement: "After two half-lives all of the isotope has decayed."
    Each half-life halves what is left: after two half-lives a quarter (25%) remains.
12. Correct this statement: "Bird wings and insect wings are homologous because both are used for flying."
    They are analogous: same job, different structure and origin, produced by convergent evolution.
13. Correct this statement: "New Zealand's plants and animals are all here because they rode Zealandia away from Gondwana."
    Some groups are Gondwanan, but DNA shows many arrived later across the sea, after much of Zealandia had been under water.

Answer key (for parents and tutors)

1. Using the table, find the percentage increase in cranial capacity from Homo habilis to Homo erectus, to the nearest whole number.
   1050 − 610 = 440, and 440 ÷ 610 × 100 = 72%.
2. Where is the foramen magnum in a fully bipedal hominin?
   Central, underneath the skull, so the head balances on the spine.
3. Explain how the angled femur helps bipedal walking.
   It brings the knees and feet under the body's centre of gravity, so the body does not sway sideways with each step.
4. Which grip is used to hold a pen?
   The precision grip: thumb tip against the fingertips.
5. Is a chimpanzee a hominid, a hominin, or both?
   A hominid only: hominins are the human line after the split from chimpanzees.
6. Describe two trends shown by the teeth and jaws from A to C.
   The tooth row changed from a U-shape with parallel sides to a parabolic curve; canines became smaller with no diastema; jaws and teeth became smaller and the face flatter (Achieved for two).
7. Calculate the percentage increase in cranial capacity from B to C, to the nearest whole number.
   1300 − 1050 = 250, and 250 ÷ 1050 × 100 = 24% (Achieved).
8. Explain why the brain could only enlarge after the diet changed.
   Brain tissue uses a lot of energy (about 20% of a resting human's energy for about 2% of body mass), so a bigger brain could only be supported once hominins ate energy-rich food such as meat and marrow, cut with tools and later cooked, which also meant smaller teeth and jaws were enough (Merit).
9. Discuss one advantage and one disadvantage of a larger brain for hominins, linking each to a selection pressure.
   Advantage: a larger brain allowed planning, better tools, cooperation and language, so individuals could hunt, share food and survive changing climates, and these were selected in a variable, competitive environment. Disadvantage: the large head makes birth difficult through a pelvis narrowed for bipedal walking, so babies are born helpless and need long care, and the brain's energy demand risks starvation when food is short. The trend continued because the survival benefit outweighed these costs (Excellence: links both sides to selection and to bipedalism).
10. Correct this statement: "Humans evolved from chimpanzees."
    Humans and chimpanzees share a common ancestor that lived about 6 to 7 million years ago; neither is the other's ancestor.
11. Correct this statement: "The foramen magnum moved to the back of the skull in bipeds."
    It moved forward to a central position under the skull, so the head balances on top of the spine.
12. Correct this statement: "Hominins became bipedal because their brains got bigger."
    Bipedalism came first: australopithecines walked upright with brains of about 430 cm^3, millions of years before brains expanded.
13. Correct this statement: "The opposable thumb means apes cannot grip at all."
    Apes have opposable thumbs too, but they are short and weak, so apes lack the strong, precise grip of the fingertip pads.

Answer key (for parents and tutors)

1. Put these in order, oldest first: Mousterian, Oldowan, Upper Palaeolithic, Acheulean.
   Oldowan, Acheulean, Mousterian, Upper Palaeolithic.
2. Which tool industry first shows a symmetrical shape planned before making?
   Acheulean (the hand axe).
3. The Acheulean began about 1.76 million years ago and the Mousterian about 250 000. About how long did the Acheulean last, in years?
   1 760 000 − 250 000 = 1 510 000 years, about 1.51 million years.
4. Give the indirect evidence that clothing is at least 83 000 years old.
   DNA shows body lice, which live in clothing, split from head lice at least 83 000 years ago.
5. Name one biological change that cooking may have allowed.
   Smaller teeth and jaws (or a shorter gut, or a larger brain supported by more energy).
6. Describe two uses of fire other than cooking.
   Warmth and light at night; protection from predators; hardening wooden spear tips; a social centre where people gathered (Achieved for two).
7. Explain how fire helped hominins move into colder environments.
   Fire kept people warm without thick body hair, so they could survive cold nights and winters and live in caves in cooler regions, which let them spread to places their bodies alone could not cope with (Merit).
8. Explain how cooking could have affected the biological evolution of hominins.
   Cooked food is softer and gives more energy for less chewing and digestion, so individuals with smaller teeth, jaws and guts were not at a disadvantage, and the extra energy could support a larger, energy-hungry brain; these traits could then be selected (Merit).
9. Discuss fire as an example of positive feedback between biological and cultural evolution, including one disadvantage of relying on it.
   Using fire is a cultural change that altered selection pressures: with cooked food, smaller jaws and bigger brains became possible, and a bigger brain in turn allowed better control of fire, planning, and teaching others how to make and keep it, which spread fire use further. Each change reinforced the other, so biology and culture drove each other. A disadvantage is dependence: once bodies had smaller teeth and guts, people relied on fire and fuel to eat well, and smoke in caves and hearths exposed them to lung irritation and burns (Excellence: links cause and effect both ways and weighs a disadvantage).
10. Correct this statement: "Cultural evolution is the same as biological evolution, just about tools."
    Cultural evolution passes on learned behaviour by teaching and imitation; it changes no alleles directly and is much faster.
11. Correct this statement: "Each tool industry was used only by one species."
    Industries overlapped: early Homo sapiens and Neanderthals both made Mousterian-style tools, so link tools to the main makers, not only one.
12. Correct this statement: "Farming made people healthier straight away."
    Early farmers were often shorter, with more tooth decay and disease than hunter-gatherers, even though there were more of them.
13. Correct this statement: "Fire was used to cook as soon as Homo habilis appeared."
    The earliest likely evidence for controlled fire is about 1 million years ago, linked to Homo erectus, long after Homo habilis appeared.

Answer key (for parents and tutors)

1. Which hominin was the first known to leave Africa, and about when?
   Homo erectus, about 1.8 million years ago (Dmanisi, Georgia).
2. From which parent do you inherit your mitochondrial DNA?
   Your mother only.
3. A haploid human genome is about 3.1 billion bases. How many bases is 4% Denisovan DNA?
   0.04 × 3.1 billion = 0.124 billion = 124 million bases.
4. Explain why African populations are the most genetically diverse.
   Humans have lived in Africa longest, so more mutations have built up there, and everyone outside Africa descends from small groups that carried only part of that diversity (founder effects).
5. Put these in order of first settlement: Aotearoa, Tonga, the Society Islands.
   Tonga (Lapita, about 2800 years ago), the Society Islands (about 1025 to 1120 CE), then Aotearoa (about 1250 to 1300 CE).
6. Describe the Out of Africa (replacement) model.
   Homo sapiens evolved in Africa only, then spread to the rest of the world and replaced the earlier hominins living there, with little or no interbreeding (Achieved).
7. Explain how mtDNA evidence supports an African origin for Homo sapiens.
   mtDNA is inherited from the mother without recombination, so lineages can be traced back; all human mtDNA traces to an ancestor in Africa, African populations hold the most diversity because people have lived there longest, and non-African lineages form one branch within the African ones, fitting a small founding group leaving Africa (Merit).
8. Explain why Papuans carry Denisovan DNA but most Europeans do not.
   The ancestors of Papuans travelled east through Asia, where Denisovans lived, and interbred with them before reaching New Guinea; the ancestors of Europeans moved west, where there were Neanderthals but few or no Denisovans, so they gained Neanderthal DNA but not Denisovan (Merit).
9. Discuss whether the evidence supports a strict replacement model, the multiregional model, or something between.
   The African fossils, the mtDNA tree and the fall in diversity away from Africa support a recent African origin, which the multiregional model cannot explain, because separate regional evolution would not produce a single African-rooted tree or the serial founder pattern. But the 1 to 2% Neanderthal and 4 to 6% Denisovan DNA shows that the replacement was not total: Homo sapiens interbred with the hominins it met. So the evidence supports something between, a mostly African origin with limited interbreeding (assimilation), with the small percentages showing that most of our genome is still African in origin (Excellence).
10. Correct this statement: "Homo sapiens was the first hominin to leave Africa."
    Homo erectus left Africa about 1.8 million years ago, long before Homo sapiens evolved.
11. Correct this statement: "Mitochondrial Eve was the only woman alive at the time."
    Many women lived then; only her mtDNA line happens to survive, because other lines ended with women who had no daughters.
12. Correct this statement: "Mitochondrial DNA comes from both parents."
    mtDNA comes only from the mother, through the egg's mitochondria; the Y chromosome traces the father's line.
13. Correct this statement: "The Out of Africa model is wrong because people carry Neanderthal DNA."
    The origin was still African; the DNA shows a small amount of interbreeding, so the replacement was not complete.

Answer key (for parents and tutors)

1. A sheep flock averages 4.0 kg of wool per sheep. Parents chosen average 5.0 kg, and $h^2 = 0.40$. Predict the offspring average.
   S = 5.0 − 4.0 = 1.0 kg; R = 0.40 × 1.0 = 0.40 kg; offspring average 4.0 + 0.40 = 4.4 kg.
2. EcoRI cuts this 35-base strand after the G in each GAATTC. Give the fragment lengths: CCTGA ATTCA GGCTA ATCGG CATGA ATTCA TGGCA
   GAATTC starts at base 4 and base 24, so cuts after bases 4 and 24: fragments of 4, 24 − 4 = 20 and 35 − 24 = 11 bases.
3. A gene from a bacterium is put into maize so the maize makes an insect toxin. Name this kind of manipulation.
   Transgenesis: a gene from another species is inserted.
4. Why does a field of cloned plants risk being wiped out by one new disease?
   All the plants carry the same alleles, so none has resistance the others lack; if the pathogen can infect one, it can infect all.
5. A patient's bone marrow cells are edited to treat sickle cell disease. Will the change pass to the patient's children?
   No: bone marrow cells are somatic cells, so the change is not in eggs or sperm.
6. Correct this statement: "Selective breeding creates new genes for the traits we want."
   Selective breeding only changes how common existing alleles are; new alleles come from mutation.
7. Correct this statement: "Gene therapy on a patient's blood cells will be passed on to their children."
   Somatic gene therapy changes body cells only; only germline changes reach eggs or sperm.
8. Correct this statement: "A clone of a prize bull will look and perform exactly the same."
   A clone has the same genes, but environment, nutrition and epigenetic effects still change its phenotype.
9. Correct this statement: "Gene editing is banned in New Zealand."
   It is regulated, not banned: under the HSNO Act any genetically modified organism needs EPA approval, including gene-edited ones.

Answer key (for parents and tutors)

1. 1.325 g of anhydrous sodium carbonate ($M = 106.0$ g mol^{-1}) is made up to 250.0 mL. What is its concentration?
   $n = 1.325 \div 106.0 = 0.01250$ mol; $c = 0.01250 \div 0.2500 = 0.0500$ mol L^{-1}.
2. 20.00 mL of that solution needs 21.60 mL of hydrochloric acid: $Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$. What is the acid's concentration?
   $n(Na_2CO_3) = 0.0500 \times 0.02000 = 1.000 \times 10^{-3}$ mol, so $n(HCl) = 2 \times 1.000 \times 10^{-3} = 2.000 \times 10^{-3}$ mol; $c = 2.000 \times 10^{-3} \div 0.02160 = 0.0926$ mol L^{-1}.
3. Titres of 18.35, 18.70, 18.40 and 18.30 mL were recorded. What mean titre should be used?
   18.70 mL is not concordant; the mean of 18.35, 18.40 and 18.30 is 18.35 mL.
4. A 2.00 g sample of impure ascorbic acid contains 1.76 g of $C_6H_8O_6$. What is its percentage purity?
   $1.76 \div 2.00 \times 100 = 88.0\%$.
5. A student forgot to rinse the burette with iodine solution, leaving it wet with water. Would the vitamin C results come out too high or too low?
   Too high: the water dilutes the iodine, so a bigger titre is needed, and the calculation (using the standardised concentration) gives more moles of vitamin C than were really there.
6. Correct this statement: "I rinsed the conical flask with the juice so it would not be diluted."
   Rinse the flask with distilled water only; extra juice clinging to it would add moles beyond the 25.00 mL pipetted.
7. Correct this statement: "My titres were 13.25, 13.15 and 13.80 mL, so the mean titre is 13.40 mL."
   Average only concordant titres: 13.80 mL is not within 0.20 mL, so the mean is 13.20 mL.
8. Correct this statement: "The 10.00 mL portion contained 2.809×10^{-4} mol, so the tablet contained 0.0494 g."
   Scale up by the dilution: the 100.0 mL flask held ten times as much, 2.809×10^{-3} mol, which is 0.494 g.
9. Correct this statement: "My results were very precise, so they must be accurate."
   Precise means repeatable; a systematic error such as an unstandardised titrant shifts every titre the same way and leaves them inaccurate.

Answer key (for parents and tutors)

1. A C_3H_8O alcohol has a broad IR dip at 3350 cm^{-1} and two peaks in its ^{13}C NMR spectrum. Name it.
   Two peaks means two carbon environments, so it is propan-2-ol, $CH_3CH(OH)CH_3$ (propan-1-ol has three).
2. How many peaks does pentan-3-one, $CH_3CH_2COCH_2CH_3$, give in its ^{13}C NMR spectrum?
   The molecule is symmetrical about the C=O: the two CH_3 are equivalent and the two CH_2 are equivalent, so 3 peaks (CH_3, CH_2 and C=O).
3. A haloalkane has molecular ion peaks at m/z 78 and 80 in a 3 : 1 ratio. Which halogen is present, and what is the molecular formula?
   Two peaks 2 apart in a 3 : 1 ratio show chlorine; 78 − 35 = 43 = C_3H_7, so C_3H_7Cl.
4. An ester $C_4H_8O_2$ has its base peak at m/z 43, a CH_3CO^+ ion. Is it ethyl ethanoate or methyl propanoate?
   Ethyl ethanoate, $CH_3COOCH_2CH_3$, which breaks to CH_3CO^+ (m/z 43); methyl propanoate would give $CH_3CH_2CO^+$ at m/z 57.
5. Which IR evidence shows a sample is propanal and not propan-1-ol?
   A strong sharp C=O dip near 1730 cm^{-1} and no broad O–H dip at 3200 to 3550 cm^{-1}.
6. Correct this statement: "The tallest peak in the mass spectrum is the molecular ion, so M = 43."
   The tallest peak is the base peak, the most common fragment; the molecular ion is the last big peak on the right.
7. Correct this statement: "Propan-2-ol has three carbons, so its ^{13}C NMR spectrum has three peaks."
   The two CH_3 groups are equivalent, so there are two carbon environments and two peaks.
8. Correct this statement: "There is a dip at 3000 cm^{-1}, so the compound has an O–H group."
   C–H dips sit at 2850 to 3000 cm^{-1} in almost every compound; an alcohol O–H is a broad dip at 3200 to 3550 cm^{-1}.
9. Correct this statement: "A C=O dip at 1715 cm^{-1} means it is a ketone."
   Aldehydes, acids, esters and amides all have C=O too; check for O–H or N–H in IR and for the C=O shift in the ^{13}C spectrum.

Answer key (for parents and tutors)

1. Write the balanced equation for urea hydrolysing in the soil.
   $(NH_2)_2CO + H_2O \rightarrow 2NH_3 + CO_2$.

2. What happens to the equilibrium yield of ammonia if the pressure is increased, and why?
   The yield increases: the forward reaction turns 4 mol of gas into 2 mol, so the equilibrium shifts right to reduce the pressure.

3. Overall, $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$ and $N_2 + 3H_2 \rightarrow 2NH_3$. What is the minimum mass of CO_2 released in making 1.00 tonne of NH_3?
   4 mol H_2 make 8/3 mol NH_3 for each mol of CO_2, so $n(CO_2) = 3/8 \times n(NH_3)$; $n(NH_3) = 1.00 \times 10^6 \div 17.0 = 5.882 \times 10^4$ mol, $n(CO_2) = 0.375 \times 5.882 \times 10^4 = 2.206 \times 10^4$ mol, $m = 2.206 \times 10^4 \times 44.0 = 9.71 \times 10^5$ g = 0.971 t (real plants release more, because they also burn gas for heat).

4. If ocean pH fell from 8.1 to 7.8, by what factor would $[H_3O^+]$ increase?
   $10^{0.3} = 2.0$, so $[H_3O^+]$ doubles.

5. Why does the Haber process use a catalyst, when it does not change the equilibrium yield?
   It lowers the activation energy, so equilibrium is reached quickly at a lower temperature than would otherwise be needed, which keeps the yield higher and saves energy.

6. Correct this statement: "The catalyst increases the yield of ammonia."
   A catalyst speeds up the forward and reverse reactions equally, so equilibrium is reached faster but the yield at equilibrium is the same.

7. Correct this statement: "Plants use a high temperature because the Haber process needs heat."
   The forward reaction is exothermic, so heat lowers the yield; the high temperature is only there to give a fast enough rate.

8. Correct this statement: "Urea fertiliser releases nitrate, which harms the environment."
   Give the chain with equations: urease makes ammonia, bacteria oxidise it to nitrate, and nitrate leaches because soil does not hold negative ions.

9. Correct this statement: "The report lists five problems with fertiliser, so it is an evaluation."
   An evaluation weighs consequences against each other and against the benefits, and reaches a judgement backed by the chemistry.

Answer key (for parents and tutors)

1. Write the electron configuration of titanium (Z = 22).
   $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^2\ 4s^2$, or [Ar] $3d^2\ 4s^2$.

2. Write the electron configuration of Fe^{2+} (Z = 26).
   Iron is [Ar] $3d^6\ 4s^2$; the two 4s electrons go first, so Fe^{2+} is [Ar] $3d^6$.

3. Which is larger, a magnesium atom or a Mg^{2+} ion?
   The Mg atom: Mg^{2+} has lost its whole third shell, and its 12 protons pull the remaining 10 electrons in closer.

4. Which has the higher first ionisation energy, phosphorus or sulfur?
   Phosphorus: its three 3p electrons are unpaired, while sulfur's fourth 3p electron is paired, and the repulsion makes it easier to remove.

5. Put nitrogen, oxygen and fluorine in order of increasing electronegativity.
   N < O < F: across Period 2 the nuclear charge increases while the shell stays the same.

6. Write the electron configurations of vanadium, V (Z = 23), and Ni^{2+} (Z = 28), using s, p, d notation.
   V: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^3\ 4s^2$; Ni: [Ar] $3d^8\ 4s^2$, so Ni^{2+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^8$ (Achieved for both correct).

7. Explain why the first ionisation energy of aluminium (578 kJ mol^{-1}) is lower than that of magnesium (738 kJ mol^{-1}).
   Magnesium's outer electron is in 3s and aluminium's is in 3p. The 3p electron is higher in energy and is partly shielded from the nucleus by the $3s^2$ electrons, so although aluminium has one more proton, its 3p electron is held less tightly and less energy is needed to remove it (Merit links the subshell to the shielding; Excellence also explains why the extra proton does not outweigh it).

8. The K^+ ion has a radius of 138 pm and the Cl^- ion 181 pm. Explain why K^+ is smaller, even though both ions have the same number of electrons.
   Both ions have 18 electrons as $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$, so the same number of shells and the same shielding. K^+ has 19 protons and Cl^- only 17, so the nucleus of K^+ attracts the same electron cloud more strongly and pulls it closer, making K^+ smaller (Excellence names what is the same as well as the difference in protons).

9. Justify the trend in electronegativity from chlorine (3.16) to bromine (2.96) to iodine (2.66).
   Down group 17 each atom has an extra shell (Cl three, Br four, I five), so the bonding pair is further from the nucleus and more shielded by inner electrons. Although the number of protons increases, the greater distance and shielding weaken the attraction for the bonding electrons, so electronegativity decreases from 3.16 to 2.96 to 2.66 (Excellence uses all of protons, shells, shielding and attraction).

10. Correct this statement: "Fe^{2+} is [Ar] $3d^4\ 4s^2$, because the last electrons in are the first out."
    Transition metals lose 4s electrons first: Fe^{2+} is [Ar] $3d^6$.

11. Correct this statement: "Atomic radius gets bigger across a period because there are more electrons."
    The extra electrons go into the same shell while protons increase, so the radius gets smaller.

12. Correct this statement: "Chromium is [Ar] $3d^4\ 4s^2$, following the filling order."
    Chromium is [Ar] $3d^5\ 4s^1$ and copper is [Ar] $3d^{10}\ 4s^1$: a half-full or full 3d is more stable.

13. Correct this statement: "Ionisation energy decreases down a group because there are more protons."
    There are more protons, but the outer electron is in a higher shell, further away and more shielded, which outweighs the extra protons.

Answer key (for parents and tutors)

1. XeF_2 has 2 bonding regions and 3 lone pairs on xenon. What is its shape?
   Linear: the 3 lone pairs take the equatorial positions of a trigonal bipyramid, leaving the two F atoms opposite each other at 180°.

2. What is the shape and bond angle of $SiCl_4$?
   Tetrahedral, 109.5°: 4 bonding regions and no lone pairs on Si.

3. What is the shape of BrF_5?
   Square pyramid: 6 regions, 5 bonding and 1 lone pair.

4. Is PCl_5 polar or non-polar?
   Non-polar: the P–Cl bonds are polar, but the trigonal bipyramid is symmetrical and the dipoles cancel.

5. Which attractions act between CH_3Cl molecules?
   Temporary dipole and permanent dipole attractions; no hydrogen bonding, because no H is bonded to N, O or F.

6. Draw the Lewis structure of the ICl_4^- ion and name its shape.
   Electrons: 7 + 4 × 7 + 1 = 36 (18 pairs); 4 I–Cl bonds, 3 lone pairs on each Cl, 2 lone pairs on I. Six regions in an octahedral arrangement with the lone pairs opposite, so the shape is square planar (Achieved for the structure or shape, Merit for both).

7. Explain why the bond angle in NH_3 is about 107°, while in BF_3 it is 120°.
   NH_3 has 4 regions (3 bonding pairs and 1 lone pair), which repel into a tetrahedral arrangement; the lone pair repels more strongly than bonding pairs, squeezing the angle from 109.5° to about 107°. BF_3 has only 3 bonding regions and no lone pair, so they spread to 120° in a trigonal planar shape (Excellence compares the number of regions and the effect of the lone pair).

8. ClF_3 is polar but PCl_5 is non-polar. Explain why.
   Both have polar bonds, as F and Cl are more electronegative than the central atoms. ClF_3 is T-shaped because two lone pairs occupy equatorial positions, so its three dipoles are not symmetrical and do not cancel; PCl_5 has no lone pairs and is a symmetrical trigonal bipyramid, so its five dipoles cancel.

9. Ethanol, CH_3CH_2OH (46 g mol^{-1}), boils at 78 °C, methoxymethane, CH_3OCH_3 (46 g mol^{-1}), at –24 °C, and propane, C_3H_8 (44 g mol^{-1}), at –42 °C. Justify the order of boiling points.
   The three molecules have similar numbers of electrons, so their TD attractions are similar. Propane is non-polar with TD attractions only, so it boils lowest. Methoxymethane has polar C–O bonds in a bent C–O–C, so it adds PD attractions and boils higher. Ethanol has an O–H group, so it also forms hydrogen bonds, the strongest attractions here, so far more energy is needed to separate its molecules and it boils highest, at 78 °C (Excellence links each attraction to its strength with the similar electron clouds as the control).

10. Correct this statement: "XeF_4 has six regions, so its shape is octahedral."
    The arrangement of regions is octahedral, but the shape names only the atoms: with two lone pairs, XeF_4 is square planar.

11. Correct this statement: "When water boils, the O–H bonds break."
    Boiling overcomes the hydrogen bonds between molecules; the covalent O–H bonds inside each molecule stay intact.

12. Correct this statement: "CH_3Cl contains a hydrogen atom and a chlorine atom, so it has hydrogen bonding."
    Hydrogen bonding needs H bonded directly to N, O or F; CH_3Cl has only TD and PD attractions.

13. Correct this statement: "XeF_4 has polar bonds, so it is a polar molecule."
    Its square planar shape is symmetrical, so the four equal Xe–F dipoles cancel out, giving a non-polar molecule.

Answer key (for parents and tutors)

1. Butane (a straight chain) and 2-methylpropane (branched) are both C_4H_{10}. Which has the higher boiling point?
   Butane: the same number of electrons, but the straight chain has more surface contact, so stronger temporary dipole attractions (it boils at −0.5 °C against −12 °C).

2. Which is more soluble in water: sodium chloride or iodine?
   Sodium chloride: water's polar molecules form ion–dipole attractions with Na^+ and Cl^-, while non-polar iodine cannot replace water's hydrogen bonds.

3. What is the sign of ΔS (system) for $H_2O(l) \rightarrow H_2O(g)$?
   Positive: gas particles are far more spread out than liquid.

4. What is the sign of ΔS (system) for $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$?
   Negative: 4 mol of gas become 2 mol.

5. A reaction is endothermic and its system entropy decreases. When is it spontaneous?
   Never: the system's entropy falls and the surroundings' entropy falls too, so the total cannot increase at any temperature.

6. Magnesium oxide melts at 2825 °C and iodine at 114 °C. Explain the difference in terms of the particles and the attractions between them.
   MgO is an ionic lattice of Mg^{2+} and O^{2-} ions; melting must overcome very strong electrostatic attractions between ions with 2+ and 2− charges throughout the lattice, which needs a great deal of energy. Iodine is molecular: melting overcomes only the temporary dipole attractions between I_2 molecules, which are much weaker, so far less energy is needed (Merit names both particles and both attractions; Excellence compares their strengths).

7. Explain why iodine dissolves in hexane but hardly at all in water.
   Iodine and hexane are both non-polar with only temporary dipole attractions, so the attractions formed between I_2 and hexane are similar to those broken, and iodine dissolves. To dissolve in water, I_2 would have to break water's hydrogen bonds but could form only weak temporary dipole attractions with water, so it hardly dissolves.

8. Hydrogen peroxide decomposes: $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$, $\Delta rH = -196$ kJ mol^{-1}. State the sign of the entropy change of the system, and decide whether the reaction is spontaneous at all temperatures.
   Positive: 2 mol of liquid produce 2 mol of liquid and 1 mol of gas. It is exothermic, so the entropy of the surroundings also increases; both increase, so the total entropy always increases and the reaction is spontaneous at all temperatures (it is slow without a catalyst).

9. Dinitrogen tetroxide decomposes: $N_2O_4(g) \rightarrow 2NO_2(g)$, $\Delta rH = +57$ kJ mol^{-1}. Using the entropy change of the system and of the surroundings, justify why it happens on its own only at higher temperatures.
   One mole of gas becomes two, so the entropy of the system increases. The reaction is endothermic, so it absorbs heat from the surroundings and their entropy decreases; this decrease is larger when the surroundings are cold. At low temperature the surroundings' decrease outweighs the system's increase, so total entropy falls and the reaction is not spontaneous; at higher temperature the surroundings' decrease is smaller, the system's increase wins, and the reaction is spontaneous (Excellence weighs both changes and links them to temperature).

10. Correct this statement: "Iodine melts at 114 °C because its covalent I–I bonds are weak."
    Melting overcomes the temporary dipole attractions between I_2 molecules; the I–I bond inside each molecule does not break.

11. Correct this statement: "Endothermic reactions cannot be spontaneous."
    An endothermic change is spontaneous if the system's entropy increase outweighs the surroundings' decrease, like ice melting at 10 °C.

12. Correct this statement: "Iodine does not dissolve in water because iodine is non-polar and repels water."
    Dissolving would break strong hydrogen bonds between water molecules and replace them with only weak attractions to I_2.

13. Correct this statement: "$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ has a positive ΔS because the SO_3 molecules are bigger."
    Three moles of gas become two, so the system's entropy decreases and ΔS is negative.

Answer key (for parents and tutors)

1. How much energy is needed to heat 500 g of water from 18.0 °C to 100.0 °C?
   $q = 500 \times 4.18 \times 82.0 = 171\,380$ J = 171 kJ.

2. 50.0 mL of 1.00 mol L^{-1} HCl and 50.0 mL of 1.00 mol L^{-1} NaOH are mixed and warm by 6.7 °C. Take the mass as 100 g and c = 4.18 J g^{-1} $°C^{-1}$. What is ΔrH per mole of water formed?
   $q = 100 \times 4.18 \times 6.7 = 2800.6$ J = 2.80 kJ; $n(H_2O) = 1.00 \times 0.0500 = 0.0500$ mol; ΔrH = −2.80 ÷ 0.0500 = −56 kJ mol^{-1} (2 significant figures, set by 6.7).

3. Write the equation for the standard enthalpy of formation of ethanol, $C_2H_5OH(l)$.
   $2C(s) + 3H_2(g) + ½O_2(g) \rightarrow C_2H_5OH(l)$.

4. A substance has ΔfusH = 15.5 kJ mol^{-1} and ΔvapH = 41.6 kJ mol^{-1} at the same temperature. What is ΔsubH?
   ΔsubH = 15.5 + 41.6 = 57.1 kJ mol^{-1}.

5. Use the ΔfH table to calculate ΔcH of methanol: $CH_3OH(l) + 1½O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$.
   ΔcH = [−393.5 + 2(−285.8)] − (−239.5) = −965.1 + 239.5 = −725.6 kJ mol^{-1}.

6. Calculate ΔfH of ethyne, $C_2H_2(g)$, given ΔcH(C_2H_2) = −1300 kJ mol^{-1}, ΔcH(C) = −394 kJ mol^{-1} and ΔcH(H_2) = −286 kJ mol^{-1}.
   Target $2C(s) + H_2(g) \rightarrow C_2H_2(g)$. Use $2 \times (C + O_2 \rightarrow CO_2)$, $1 \times (H_2 + ½O_2 \rightarrow H_2O)$, and the reversed combustion of C_2H_2: ΔfH = 2(−394) + (−286) − (−1300) = −788 − 286 + 1300 = +226 kJ mol^{-1} (Merit for the method with one error; Excellence for +226 kJ mol^{-1} with sign and unit).

7. Calculate ΔrH for making liquid methanol: $CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$.
   ΔrH = ΔfH(CH_3OH) − [ΔfH(CO) + 2(0)] = −239.5 − (−110.5) = −129.0 kJ mol^{-1}.

8. Burning 1.20 g of methanol (M = 32.0 g mol^{-1}) heats 250 g of water from 19.5 °C to 34.0 °C. Calculate the experimental ΔcH of methanol.
   $q = 250 \times 4.18 \times 14.5 = 15\,152.5$ J = 15.15 kJ; n = 1.20 ÷ 32.0 = 0.0375 mol; ΔcH = −15.15 ÷ 0.0375 = −404 kJ mol^{-1}, far less negative than −725.6 kJ mol^{-1} because of heat losses and incomplete combustion.

9. Explain why ΔcH of methanol is less negative when the water formed is a gas, and calculate its value, using ΔvapH(H_2O) = +44.0 kJ mol^{-1}.
   When water vapour condenses, hydrogen bonds form between the molecules and energy is released; if the water stays as a gas, that energy is not released, so less heat is given out overall. Each mole of methanol makes 2 mol of water: ΔcH = −725.6 + 2(44.0) = −637.6 kJ mol^{-1} (Excellence links the energy to attractions forming between water molecules).

10. Correct this statement: "q = 0.920 × 4.18 × 21.5, using the mass of ethanol burned."
    m is the mass of the water being heated, 200 g; the mass of fuel is used only to find n.

11. Correct this statement: "ΔcH = q ÷ n = +899 kJ mol^{-1}."
    The water gained heat, so the reaction released it: ΔcH = −q ÷ n = −899 kJ mol^{-1}.

12. Correct this statement: "ΔrH = ΣΔfH(reactants) − ΣΔfH(products)."
    It is products minus reactants, each ΔfH multiplied by its coefficient.

13. Correct this statement: "When I reversed the methane combustion equation I kept ΔH = −890.3 kJ mol^{-1}."
    Reversing an equation changes the sign: it becomes +890.3 kJ mol^{-1}.

Answer key (for parents and tutors)

1. Name $CH_3CH_2CH_2COCl$.
   Butanoyl chloride.
2. Name $CH_3CH(CH_3)CH_2CHO$.
   3-methylbutanal: the CHO carbon is C1 and the branch is on C3.
3. Which of these has optical isomers: propan-2-ol, butan-2-ol, butanone or but-1-ene?
   Butan-2-ol: C2 carries H, OH, CH_3 and CH_2CH_3.
4. Which of these has geometric isomers: pent-1-ene, pent-2-ene, 2-methylbut-2-ene or pentane?
   Pent-2-ene: each C of the C=C has an H and a different alkyl group.
5. How many aldehydes and ketones have the formula C_4H_8O?
   Three: butanal, 2-methylpropanal and butanone.
6. Name the ester $CH_3CH_2COOCH_3$, another isomer of $C_4H_8O_2$.
   Methyl propanoate (Achieved).
7. Name the branched carboxylic acid with this formula.
   2-methylpropanoic acid, $(CH_3)_2CHCOOH$ (Achieved).
8. Which of the three compounds above exists as enantiomers?
   3-hydroxybutanal: C3 carries H, OH, CH_3 and CH_2CHO, four different groups, so it has two non-superimposable mirror images that rotate plane-polarised light in opposite directions (Merit with the reason).
9. Explain why butanoic acid boils at 164 °C and ethyl ethanoate at 77 °C.
   Both are $C_4H_8O_2$, so dispersion forces are similar. Butanoic acid has an O-H group, so its molecules hydrogen bond to each other; ethyl ethanoate has no O-H, so it has only permanent dipole attractions, which are weaker. More energy is needed to separate the acid molecules (Merit; Excellence also notes the acid forms hydrogen-bonded pairs and that size cannot explain the gap).
10. Give a test that tells butanoic acid from ethyl ethanoate, with the observation.
    Add sodium carbonate solution: butanoic acid fizzes, giving CO_2, because it is an acid; ethyl ethanoate does not react (Achieved for the observation, Merit for the reason).
11. Correct this statement: "But-1-ene has cis and trans isomers because it has a C=C bond."
    Each carbon of the C=C needs two different groups; C1 of but-1-ene has two H atoms, so it has no geometric isomers.
12. Correct this statement: "$CH_3COOCH_2CH_3$ is ethanoyl ethyl, or ethyl ester ethanoate."
    Name an ester alkyl first, then the acid part: ethyl ethanoate.
13. Correct this statement: "Enantiomers have different boiling points because they are different compounds."
    Enantiomers have identical physical properties; only the direction they rotate plane-polarised light differs.
14. Correct this statement: "The carbon in a C=O or CH_3 group can be an asymmetric carbon."
    An asymmetric carbon has four single bonds to four different groups, so a C=O carbon or a CH_3 carbon never qualifies.

Answer key (for parents and tutors)

1. Name the organic product when 2-bromobutane is heated with KOH(aq).
   Butan-2-ol: OH^- replaces Br.
2. Name the organic product when propanoic acid reacts with $SOCl_2$.
   Propanoyl chloride, CH_3CH_2COCl, with SO_2 and HCl.
3. Name the organic product when ethanoyl chloride reacts with propan-1-ol.
   Propyl ethanoate, $CH_3COOCH_2CH_2CH_3$, with HCl.
4. Give the organic products when propanamide is heated with NaOH(aq).
   The propanoate ion, $CH_3CH_2COO^-$, and ammonia, NH_3.
5. What is seen when water is added to ethanoyl chloride, and why?
   Steamy fumes: the acyl chloride is hydrolysed to ethanoic acid and HCl gas, which forms droplets with moisture in the air.
6. Name compound A, and say what it does to damp red litmus paper.
   A is propan-1-amine, $CH_3CH_2CH_2NH_2$; it turns damp red litmus blue because its N lone pair accepts a proton from water, releasing OH^- (Achieved; Merit with the reason).
7. Name compound B.
   B is propan-1-ol (Achieved).
8. Compound C reacts with A. Name the organic product and the type of link it contains.
   $CH_3CH_2COCl + CH_3CH_2CH_2NH_2 \rightarrow CH_3CH_2CONHCH_2CH_2CH_3 + HCl$: N-propylpropanamide, which contains an amide (peptide-type) link (Achieved for the name, Merit with the equation).
9. Compound C reacts with B. Name the organic product.
   Propyl propanoate, $CH_3CH_2COOCH_2CH_2CH_3$ (Achieved).
10. The product from part 3 is heated under reflux with dilute HCl. Give the two organic products and explain why one of them is an ion.
    Propanoic acid, CH_3CH_2COOH, and the propylammonium ion, $CH_3CH_2CH_2NH_3^+$. Water breaks the C-N bond, and the propan-1-amine released is a base, so it accepts a proton from the excess acid and ends up as its ammonium ion (Merit; Excellence also contrasts the products in NaOH, propanoate ion and propan-1-amine, and explains the difference).
11. Correct this statement: "1-bromopropane with KOH always gives propan-1-ol."
    Only KOH(aq) gives the alcohol; KOH in alcohol mostly gives propene by elimination.
12. Correct this statement: "Hydrolysing an amide in acid gives the carboxylic acid and ammonia."
    In acid the NH_3 is protonated, so the products are the carboxylic acid and NH_4^+.
13. Correct this statement: "The ester from propanoic acid and methanol is propyl methanoate."
    The alcohol gives the first word and the acid the second: methyl propanoate.
14. Correct this statement: "An acyl chloride dissolves in water to give a solution of the acyl chloride."
    It reacts with the water, giving the carboxylic acid and HCl, seen as steamy fumes.

Answer key (for parents and tutors)

1. Name the organic product when propan-1-ol is heated under reflux with excess acidified permanganate.
   Propanoic acid: under reflux the propanal formed is oxidised further.
2. Which gives a silver mirror with Tollens' reagent: propanal or propanone?
   Propanal, the aldehyde.
3. Name the product when butanone is reduced with $NaBH_4$.
   Butan-2-ol, a secondary alcohol (as a racemic mixture).
4. Name the major product when 2-bromobutane is heated with KOH in ethanol.
   But-2-ene (cis and trans); but-1-ene is the minor product.
5. What colour change is seen when 2-methylpropan-2-ol is warmed with acidified dichromate?
   None: it stays orange, because a tertiary alcohol has no H on the C carrying the OH and is not oxidised.
6. Name compound P.
   Butan-2-ol: the only $C_4H_{10}O$ alcohol with a carbon bonded to four different groups (Achieved).
7. Name Q and give the colour change seen as it forms.
   Q is butanone; orange to green as $Cr_2O_7^{2-}$ is reduced to Cr^{3+} (Achieved; Merit for linking the colour to the oxidation of a secondary alcohol).
8. Explain why Q gives no silver mirror.
   Butanone is a ketone: its C=O carbon carries no H, so the mild oxidant in Tollens' cannot oxidise it and Ag^+ is not reduced (Merit).
9. Name R and S, and explain why R is the major product.
   R is but-2-ene, formed as cis and trans isomers; S is but-1-ene. Removing an H from C3, which has fewer H atoms than C1, gives the major product (Merit; Excellence for drawing both but-2-ene isomers and explaining why there are three products).
10. Q is reduced with $NaBH_4$. Explain why the product does not rotate plane-polarised light, although P from the bottle did.
    $NaBH_4$ adds hydrogen to the flat C=O from either side equally, so both enantiomers of butan-2-ol form in equal amounts. Their rotations cancel in this racemic mixture, whereas P from the bottle was a single enantiomer (Excellence).
11. Correct this statement: "Heating propan-1-ol under reflux with dichromate is the way to make propanal."
    Reflux returns the propanal to be oxidised again, giving propanoic acid; distil it off as it forms to keep the aldehyde.
12. Correct this statement: "With dichromate, the alcohol turns green."
    The alcohol is colourless; it is the orange $Cr_2O_7^{2-}$ that is reduced to green Cr^{3+}.
13. Correct this statement: "Butan-2-ol gives but-2-ene only when it is dehydrated."
    It gives cis- and trans-but-2-ene as major products and but-1-ene as the minor product.
14. Correct this statement: "$NaBH_4$ oxidises the ketone to an alcohol."
    $NaBH_4$ is a reductant: it adds hydrogen to the C=O, so the ketone is reduced to a secondary alcohol.

Answer key (for parents and tutors)

1. What small molecule is lost when ethane-1,2-diol and benzene-1,4-dicarboxylic acid form PET?
   Water, H_2O.
2. Give the products when nylon-6,6 is heated under reflux with HCl(aq).
   Hexanedioic acid and the hexane-1,6-diammonium ion, $^+H_3N(CH_2)_6NH_3^+$.
3. How many different dipeptides can be made from one glycine and one alanine?
   Two: Gly-Ala and Ala-Gly.
4. Give the products when glyceryl tristearate (a fat) is heated with NaOH(aq).
   Glycerol (propane-1,2,3-triol) and sodium stearate (sodium octadecanoate), three per fat molecule.
5. Which amino acid is not chiral?
   Glycine: its C2 carries two H atoms, so it has no asymmetric carbon.
6. Name the type of polymerisation that forms PLA, and the type of link in it.
   Condensation polymerisation; ester links (Achieved).
7. Explain why lactic acid exists as enantiomers.
   C2 is bonded to four different groups, H, OH, CH_3 and COOH, so the molecule has two non-superimposable mirror images that rotate plane-polarised light in opposite directions (Merit).
8. Give the organic product when PLA is heated under reflux with NaOH(aq).
   The 2-hydroxypropanoate (lactate) ion, $CH_3CH(OH)COO^-$, as sodium 2-hydroxypropanoate: every ester link is hydrolysed and OH^- removes the acid proton (Achieved for the product, Merit for the explanation).
9. Name the small molecule released when nylon-6,6 is made from the dichloride.
   HCl, hydrogen chloride (Achieved).
10. Explain why the dichloride route is faster than using hexanedioic acid.
    The C of -COCl is bonded to two electronegative atoms, O and Cl, so it is strongly δ+ and is attacked quickly by the N lone pair of the amine. The reaction is not reversible, so it goes to completion at room temperature; the acid reacts slowly and reversibly (Excellence).
11. Correct this statement: "The repeating unit of a polyester is just the ester link -COO-."
    A repeating unit contains one of each monomer, with an open bond at each end, so it shows both carbon chains and one link.
12. Correct this statement: "Glycine and alanine can only make one dipeptide."
    They can join in either order, giving Gly-Ala and Ala-Gly, which are different compounds.
13. Correct this statement: "Saponification of a fat gives glycerol and three fatty acids."
    In NaOH the acids end up as their sodium salts (soap); free fatty acids form only in acid hydrolysis.
14. Correct this statement: "Condensation polymers form when C=C bonds break open."
    That is addition polymerisation; condensation joins two different functional groups and releases a small molecule.

Answer key (for parents and tutors)

1. Write the Ks expression for $PbCl_2$.
   $Ks = [Pb^{2+}][Cl^-]^2$.

2. $Ks(BaSO_4) = 1.1 \times 10^{-10}$ at 25 °C. Calculate its solubility.
   $s = \sqrt{(1.1 \times 10^{-10})} = 1.0 \times 10^{-5}$ mol L^{-1}.

3. The solubility of CaF_2 is 2.1×10^{-4} mol L^{-1}. Calculate $Ks(CaF_2)$.
   $Ks = 4s^3 = 4 \times (2.1 \times 10^{-4})^3 = 3.7 \times 10^{-11}$.

4. What happens to the solubility of AgCl when concentrated ammonia is added, and why?
   It increases: $Ag^+ + 2NH_3 \rightarrow [Ag(NH_3)_2]^+$ removes Ag^+, so the equilibrium shifts right and more AgCl dissolves.

5. Equal volumes of 2.0×10^{-4} mol L^{-1} $AgNO_3$ and 2.0×10^{-4} mol L^{-1} NaCl are mixed. Does AgCl precipitate? $Ks(AgCl) = 1.8 \times 10^{-10}$.
   After mixing each ion is 1.0×10^{-4} mol L^{-1}, so $Q = 1.0 \times 10^{-8}$, which is greater than $Ks = 1.8 \times 10^{-10}$: yes, a precipitate forms.

6. Write the equation for the equilibrium in a saturated solution, and the Ks expression.
   $Zn(OH)_2(s) \rightleftharpoons Zn^{2+}(aq) + 2OH^-(aq)$; $Ks = [Zn^{2+}][OH^-]^2$ (Achieved).

7. Calculate the solubility of $Zn(OH)_2$ in pure water.
   $Ks = 4s^3$, so $s = \sqrt[3]{(3.0 \times 10^{-17} \div 4)} = \sqrt[3]{(7.5 \times 10^{-18})} = 1.96 \times 10^{-6}$ mol L^{-1} (Merit).

8. Calculate its solubility in a solution of pH 12.00, and explain the difference.
   $[OH^-] = 1.0 \times 10^{-2}$ mol L^{-1}, so $s = 3.0 \times 10^{-17} \div (1.0 \times 10^{-2})^2 = 3.0 \times 10^{-13}$ mol L^{-1}. The added OH^- is a common ion: it shifts the equilibrium to the left, so far less dissolves (Merit for the value with the reason).

9. When concentrated NaOH is added a little at a time, a white precipitate forms and then dissolves. Explain.
   At first, OH^- raises Q above Ks, so $Zn(OH)_2$ precipitates. With excess OH^-, the complex ion forms, $Zn^{2+} + 4OH^- \rightarrow [Zn(OH)_4]^{2-}$, which removes Zn^{2+}; Q falls below Ks, the equilibrium shifts to the right, and the precipitate dissolves (Excellence).

10. 10.0 mL of 2.0×10^{-4} mol L^{-1} $ZnSO_4$ is mixed with 10.0 mL of NaOH of pH 9.00. Will a precipitate form?
    After mixing, $[Zn^{2+}] = 1.0 \times 10^{-4}$ and $[OH^-] = 1.0 \times 10^{-5} \div 2 = 5.0 \times 10^{-6}$ mol L^{-1}, so $Q = 1.0 \times 10^{-4} \times (5.0 \times 10^{-6})^2 = 2.5 \times 10^{-15}$. Q is greater than $Ks = 3.0 \times 10^{-17}$, so a precipitate forms (Excellence for the full calculation with dilution).

11. Correct this statement: "For PbI_2, $Ks = s \times 2s = 2s^2$."
    The iodide concentration is 2s and it is squared: $Ks = s \times (2s)^2 = 4s^3$.

12. Correct this statement: "Ag_2CrO_4 has a smaller Ks than AgCl, so it must be less soluble."
    Ks values compare solubility only for solids of the same type; work out s for each.

13. Correct this statement: "Adding NaCl to saturated AgCl lowers Ks."
    Only temperature changes Ks; the common ion lowers the solubility, s.

14. Correct this statement: "Q is worked out from the concentrations of the two solutions before they are mixed."
    Mixing dilutes both, so find each ion's concentration in the total volume first.

Answer key (for parents and tutors)

1. Write the Ka expression for HCOOH.
   $K_a = [HCOO^-][H_3O^+] \div [HCOOH]$.

2. Calculate the pH of 0.050 mol L^{-1} HCOOH. Ka = 1.78×10^{-4}.
   $[H_3O^+] = \sqrt{(1.78 \times 10^{-4} \times 0.050)} = 2.98 \times 10^{-3}$ mol L^{-1}, so pH = 2.53.

3. Calculate the pH of 0.20 mol L^{-1} NH_4Cl. Ka(NH_4^+) = 5.75×10^{-10}.
   $[H_3O^+] = \sqrt{(5.75 \times 10^{-10} \times 0.20)} = 1.07 \times 10^{-5}$ mol L^{-1}, so pH = 4.97.

4. Which solution conducts better, 0.10 mol L^{-1} CH_3COOH or 0.10 mol L^{-1} CH_3COONa?
   CH_3COONa: it is fully dissociated into Na^+ and CH_3COO^- ions, while the acid is mostly molecules.

5. A buffer has $[NH_3] = [NH_4^+]$ = 0.10 mol L^{-1}. What is its pH? pKa(NH_4^+) = 9.24.
   $[NH_3] = [NH_4^+]$, so $[H_3O^+]$ = Ka and pH = pKa = 9.24.

6. Write the Ka expression for HOCl.
   $K_a = [OCl^-][H_3O^+] \div [HOCl]$ (Achieved).

7. Calculate the pH of 0.050 mol L^{-1} NaOCl.
   OCl^- is a weak base: $[H_3O^+] = \sqrt{(K_a \times K_w \div c)} = \sqrt{(2.95 \times 10^{-8} \times 1.0 \times 10^{-14} \div 0.050)} = 7.68 \times 10^{-11}$ mol L^{-1}, so pH = 10.11 (Merit).

8. List the species in 0.050 mol L^{-1} NaOCl, except water, in order of decreasing concentration.
   $Na^+ > OCl^- > HOCl = OH^- > H_3O^+$: NaOCl dissociates fully, a small fraction of OCl^- reacts, $OCl^- + H_2O \rightleftharpoons HOCl + OH^-$, giving equal small amounts of HOCl and OH^-, and $[H_3O^+]$ is tiny in a basic solution (Merit; Excellence with the reasons).

9. A pool is kept at pH 7.50. Calculate the ratio $[OCl^-] \div [HOCl]$, and say which is present in the greater amount.
   $[H_3O^+]$ = 10^−7.50 = 3.16×10^{-8} mol L^{-1}; $[OCl^-] \div [HOCl] = K_a \div [H_3O^+] = 2.95 \times 10^{-8} \div 3.16 \times 10^{-8} = 0.93$, so there is slightly more HOCl. The pH is just below the pKa, which is why pools are not allowed to drift much higher (Excellence).

10. Compare the conductivity of 0.050 mol L^{-1} NaOCl and 0.050 mol L^{-1} HOCl.
    NaOCl is a soluble salt, fully dissociated into Na^+ and OCl^-, so it conducts well. HOCl is a weak acid: very few molecules form H_3O^+ and OCl^-, so it conducts poorly (Merit; Excellence with equations for both).

11. Correct this statement: "For 0.10 mol L^{-1} CH_3COOH, $[H_3O^+]$ = 0.10 mol L^{-1}, so the pH is 1.00."
    A weak acid reacts only partly: $[H_3O^+] = \sqrt{(K_a \times c)} = 1.32 \times 10^{-3}$ mol L^{-1}, so the pH is 2.88.

12. Correct this statement: "NH_4Cl is a salt, so its solution has pH 7."
    NH_4^+ is a weak acid, so NH_4Cl solution is acidic; only salts whose ions do not react with water are neutral.

13. Correct this statement: "A buffer keeps the pH exactly constant whatever is added."
    A buffer only resists small additions; enough acid or base uses up one partner and the pH then changes sharply.

14. Correct this statement: "A weak acid conducts poorly because it is dilute."
    It conducts poorly because few of its molecules form ions; concentration and strength are separate ideas.

Answer key (for parents and tutors)

1. 25.0 mL of 0.120 mol L^{-1} CH_3COOH is titrated with 0.150 mol L^{-1} NaOH. What volume of NaOH reaches equivalence?
   $n = 0.120 \times 0.0250 = 3.00 \times 10^{-3}$ mol; $V = 3.00 \times 10^{-3} \div 0.150 = 0.0200$ L = 20.0 mL.
2. What is the pH at the half-equivalence point when NH_3 is titrated with HCl? pKa(NH_4^+) = 9.24.
   pH = pKa = 9.24.
3. Which indicator suits NH_3 titrated with HCl: methyl red or phenolphthalein?
   Methyl red: the equivalence point is about pH 5.3, inside its range of 4.4 to 6.2.
4. What is the pH at the equivalence point when HCl is titrated with NaOH?
   pH 7.00: NaCl does not react with water.
5. Name the two carbon-containing species in the buffer region of CH_3COOH titrated with NaOH.
   CH_3COOH and CH_3COO^-.
6. 20.0 mL of 0.0850 mol L^{-1} methanoic acid, HCOOH, is titrated with 0.100 mol L^{-1} NaOH. Ka(HCOOH) = 1.78×10^{-4}, pKa = 3.75. Calculate the volume of NaOH needed to reach equivalence.
   $n(HCOOH) = 0.0850 \times 0.0200 = 1.70 \times 10^{-3}$ mol, so $V = 1.70 \times 10^{-3} \div 0.100 = 17.0$ mL (Achieved).
7. Calculate the pH before any NaOH is added.
   $[H_3O^+] = \sqrt{(1.78 \times 10^{-4} \times 0.0850)} = 3.89 \times 10^{-3}$ mol L^{-1}, so pH = 2.41 (Merit).
8. State the pH after 8.50 mL of NaOH has been added, and explain why.
   pH = 3.75: 8.50 mL is half of 17.0 mL, so half the HCOOH has become $HCOO^-$; [HCOOH] = $[HCOO^-]$, so $[H_3O^+]$ = Ka and pH = pKa (Merit).
9. Calculate the pH at the equivalence point.
   $[HCOO^-] = 1.70 \times 10^{-3} \div 0.0370 = 0.0459$ mol L^{-1}; $[H_3O^+] = \sqrt{(1.78 \times 10^{-4} \times 1.0 \times 10^{-14} \div 0.0459)} = 6.23 \times 10^{-9}$ mol L^{-1}, so pH = 8.21 (Excellence).
10. Choose phenolphthalein or methyl orange for this titration, and justify your choice.
    Phenolphthalein: $HCOO^-$ is a weak base, so the equivalence point is above 7 (8.21). The steep section runs from about pH 6.3 one drop (0.05 mL) before equivalence to about 10.1 one drop after, and phenolphthalein's range, 8.3 to 10.0, lies inside it, so although 8.3 is just above 8.21, the first lasting pink appears within one drop of equivalence. Methyl orange, 3.1 to 4.4, would change in the buffer region around pH 3.75, long before equivalence (Excellence).
11. Calculate the pH after 20.0 mL of NaOH has been added.
    Excess OH^- = $0.100 \times 0.0030 = 3.0 \times 10^{-4}$ mol in 40.0 mL, so $[OH^-] = 7.5 \times 10^{-3}$ mol L^{-1}, $[H_3O^+] = 1.33 \times 10^{-12}$ mol L^{-1} and pH = 11.88 (Merit).
12. Correct this statement: "The pH at the equivalence point is always 7."
    Only for strong with strong; a weak acid gives a basic salt (pH above 7) and a weak base an acidic salt (pH below 7).
13. Correct this statement: "At the half-equivalence point, pH = ½ pKa."
    At half-equivalence [HA] = $[A^-]$, so $[H_3O^+]$ = Ka and pH = pKa.
14. Correct this statement: "At equivalence, $[CH_3COO^-]$ = 0.100 mol L^{-1}, the same as the acid."
    The volume has doubled to 40.0 mL, so $[CH_3COO^-] = 0.0500$ mol L^{-1}; always use the total volume.
15. Correct this statement: "Choose an indicator whose pKa equals the pKa of the acid."
    Choose one whose range lies in the steep section around the equivalence point, not near the acid's pKa, which is in the buffer region.

Answer key (for parents and tutors)

1. Find the oxidation number of S in $S_2O_3^{2-}$.
   $2x + 3(-2) = -2$, so S = +2.
2. Calculate E°cell for Mg(s) | Mg^{2+}(aq) || Cu^{2+}(aq) | Cu(s).
   E°cell = +0.34 − (−2.37) = +2.71 V.
3. Will Fe^{3+} oxidise I^-? Give E°cell.
   Yes: E°cell = +0.77 − (+0.54) = +0.23 V, positive, so $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ is spontaneous.
4. In the zinc-copper cell, which electrode is the anode, and which way do electrons flow in the wire?
   Zinc is the anode (oxidised, negative); electrons flow from the zinc to the copper.
5. $CuSO_4$(aq) is electrolysed with graphite electrodes. What forms at each electrode?
   Copper at the cathode (Cu^{2+} is reduced before water) and oxygen gas at the anode (water is oxidised).
6. Correct this statement: "For Mg + $2Ag^+$, E°cell = 2(+0.80) − (−2.37) = +3.97 V."
   E° values are never multiplied by the coefficients: E°cell = +0.80 − (−2.37) = +3.17 V.
7. Correct this statement: "The anode is always the positive electrode."
   The anode is where oxidation happens: negative in a galvanic cell, positive in an electrolytic cell.
8. Correct this statement: "Electrons flow through the salt bridge."
   Electrons flow only in the wire; ions move through the salt bridge to keep each half-cell neutral.
9. Correct this statement: "E°cell is positive, so the reaction will happen quickly."
   A positive E°cell shows the reaction is spontaneous, not that it is fast.

Answer key (for parents and tutors)

1. Four repeats gave rises of 6.4, 6.6, 9.8 and 6.5 °C, and the notes say the lamp was bumped closer in the third run. Find the mean.
   The 9.8 °C run has a known cause (the lamp moved closer), so exclude it: (6.4 + 6.6 + 6.5) ÷ 3 = 19.5 ÷ 3 = 6.5 °C.
2. Using Aroha's line, rise = 8.4 sin θ °C, predict the rise at 50°.
   8.4 × sin 50° = 8.4 × 0.766 = 6.4 °C.
3. What is the Sun's noon elevation at Invercargill (46.4° S) at an equinox?
   90° − 46.4° = 43.6°.
4. Auckland is at 36.8° S. Find the noon elevations at the two solstices and how many times more energy per m² the summer Sun delivers.
   Summer: 90° − 36.8° + 23.4° = 76.6°; winter: 90° − 36.8° − 23.4° = 29.8°; sin 76.6° ÷ sin 29.8° = 0.973 ÷ 0.497 = 1.96 times.
5. A student increases the repeats at each angle from 3 to 5. Does this mainly improve reliability or validity?
   Reliability: more repeats give a better mean and show whether results agree, but do not change what is being measured.
6. Correct this statement: "Doing more repeats makes my data more valid."
   Repeats improve reliability; validity comes from measuring the right thing and controlling the other variables.
7. Correct this statement: "I left out the 9.0 °C reading because it did not fit my hypothesis."
   Exclude a reading only with a reason from the method (the card was still warm), and report that you did it.
8. Correct this statement: "My conclusion is that the angle of light causes the seasons."
   Conclude about what you measured (rise ∝ sin θ), then link it to the seasons as a model, with its limits.
9. Correct this statement: "My evaluation: I could have done it more carefully."
   Name the specific source of error, its effect on the data, and how you would reduce it.

Answer key (for parents and tutors)

1. A town's land is rising at 1.0 mm a year. Using 0.56 m of global rise from 2005 to 2100, find the local rise.
   Rising land reduces the local rise: 1.0 mm × 95 = 95 mm = 0.095 m, so 0.56 − 0.095 = 0.465 m, about 0.47 m.
2. How many times faster was global sea level rising in 2006 to 2018 (3.7 mm a year) than in 1901 to 1971 (1.3 mm a year)?
   3.7 ÷ 1.3 = 2.8 times faster.
3. A property developer's blog says sea level rise is exaggerated, with no data. How should you treat it in your report?
   As evidence of a stakeholder's view, not as scientific evidence: the author has a financial interest and gives no data, so check any claim against IPCC or NZ SeaRise data.
4. A council plans to move houses away from an eroding coast over 30 years. Which type of response is this?
   Managed retreat.
5. Why can parts of Wellington face a faster local rise than the global average?
   The land there is sinking, so the local rise is the global rise plus the subsidence.
6. Correct this statement: "Melting sea ice around Antarctica is a main cause of sea level rise."
   Floating ice already displaces its weight; the rise comes from warming water and from ice on land melting or sliding into the sea.
7. Correct this statement: "My personal response: I think it is a big problem and someone should fix it."
   Give a specific action, who should take it, and the evidence and values that support it.
8. Correct this statement: "Every source agreed, so I only needed three websites."
   Use a range of source types and say how reliable each is; disagreement between them is useful evidence to discuss.
9. Correct this statement: "Local sea level will rise exactly as much as the global average."
   Local rise is the global rise plus the effect of the land sinking or rising, which differs along the coast.

Answer key (for parents and tutors)

1. Charcoal has 25.0% of its original carbon-14. How old is it?
   25.0% is two half-lives: 2 × 5730 = 11,460 years.
2. Bone has 60.0% of its original carbon-14. How old is it?
   $t = 5730 \times \log_2(1 \div 0.600) = 5730 \times 0.737 = 4220$ years.
3. In a cliff, a dike cuts layers 1 to 3 and is itself offset by a fault. Which happened first, the dike or the fault?
   The dike: the fault cuts it, so the fault is younger.
4. A peat layer lies between the Taupō tephra and the Kaharoa tephra. What is its age range?
   Between about 232 CE and about 1314 CE.
5. Why can a sandstone not be dated by potassium-argon on its own grains?
   The grains crystallised in an older rock before they were eroded and deposited, so their clocks date the source rock, not the sandstone.
6. Correct this statement: "Carbon-14 dating shows the granite is 96 million years old."
   Carbon-14 only reaches about 50 000 years and dates once-living material; old igneous rocks need potassium-argon or uranium-lead.
7. Correct this statement: "After two half-lives all the parent isotope has gone."
   Half remains after one half-life and a quarter after two; the amount halves each time and never quite reaches zero.
8. Correct this statement: "The dike is older than the layers because it is underneath them."
   A dike that cuts through layers is younger than every layer it cuts.
9. Correct this statement: "A sandstone can be dated by measuring argon in its grains."
   Its grains crystallised before being eroded and deposited, so date volcanic layers above and below it instead.

Answer key (for parents and tutors)

1. Find the total pressure 500 m down. Use $\rho = 1025$ kg m^{-3}, $g = 9.8$ N kg^{-1} and air pressure 1.01×10^5 Pa.
   $\rho gh = 1025 \times 9.8 \times 500 = 5.02 \times 10^6$ Pa; total $= 5.02 \times 10^6 + 0.101 \times 10^6 = 5.12 \times 10^6$ Pa.
2. In the Southern Hemisphere a wind blows from the south, towards the north. Which way is the net Ekman transport?
   90° to the left of a northward wind: towards the west.
3. What happens to the salinity and density of surface water in the subtropics, where evaporation is strong?
   Both rise: evaporation removes water and leaves the salt behind.
4. Why does sea ice forming make the water beneath it denser?
   Ice holds little salt, so brine is rejected into the water below, making it saltier as well as near freezing.
5. Why is the thermocline near New Zealand stronger in summer than in winter?
   In summer stronger sunshine warms a thin surface layer and lighter winds mix less, so the temperature drop below it is sharp; in winter cooling and storms mix the surface deeper and the drop is gentler.
6. Describe how wind sets a surface current moving.
   Friction between the wind and the sea surface drags the top layer along; it drags the layer below, so motion passes downwards, weakening with depth (Achieved).
7. Explain how the south-westerly wind and the Coriolis effect cause upwelling along this coast.
   The wind blows north-east along the coast. In the Southern Hemisphere the Coriolis effect deflects moving water to the left, so each layer turns further left (the Ekman spiral) and the net transport is 90° to the left of the wind: north-west, offshore. Surface water moves away from the coast and cold water from below the pycnocline rises to replace it (Merit for linking wind, Coriolis and transport).
8. Explain why upwelling makes the sea green and attracts fish.
   The deep water is rich in nitrate and phosphate from decomposing matter that sank from above. Brought into the sunlit layer, these nutrients let phytoplankton photosynthesise and multiply, turning the water green; zooplankton and then fish feed on them (Merit).
9. Explain why north-easterly winds stop the upwelling.
   A north-easterly blows south-west along the coast, so Ekman transport is to its left: south-east, onshore. Surface water piles up against the coast and sinks (downwelling), the warm low-nutrient layer thickens, and the pycnocline blocks nutrients, so productivity falls (Excellence links wind direction, Coriolis, transport and nutrients for both seasons).
10. Correct this statement: "The Coriolis effect makes currents turn right in New Zealand."
    In the Southern Hemisphere moving water and air are deflected to the left.
11. Correct this statement: "Ekman transport goes the same way as the wind."
    Net Ekman transport is at right angles to the wind, to the left in the Southern Hemisphere.
12. Correct this statement: "Seawater is densest at 4 °C, so the deep ocean is at 4 °C."
    That is fresh water; normal seawater gets denser right down to about −1.9 °C, and deep water is about 0 to 4 °C.
13. Correct this statement: "The thermocline is the warm layer at the top."
    The thermocline is the transition layer where temperature falls quickly with depth, between the mixed layer and the deep layer.

Answer key (for parents and tutors)

1. If ocean pH fell from 8.10 to 7.80, by what factor would $[H^+]$ increase?
   10^(8.10 − 7.80) = 10^0.30 = 2.0 times.

2. Calculate $[H^+]$ in seawater at pH 8.1.
   $[H^+] = 10^{(-8.1)} = 7.9 \times 10^{-9}$ mol L^{-1}.

3. Using the solubility table, how many times more CO_2 dissolves at 10 °C than at 30 °C?
   2.32 ÷ 1.26 = 1.84 times.

4. Phytoplankton turn CO_2 into sugar, and their remains sink as marine snow. Which pump is this?
   The biological pump.

5. Why does adding CO_2 to seawater reduce the concentration of carbonate ions?
   The extra H^+ from carbonic acid reacts with carbonate, $H^+ + CO_3^{2-} \rightarrow HCO_3^-$, turning it into hydrogencarbonate.

6. Describe how the physical pump moves CO_2 from the air into the deep ocean.
   CO_2 dissolves at the surface, faster in cold water and where wind and waves mix the surface; sinking (downwelling) cold water carries it down away from the air (Achieved for dissolving and cold water; Merit adds wind, waves and downwelling).

7. Explain how the biological pump removes carbon from surface water.
   Phytoplankton photosynthesise, $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$, making organic carbon that passes through the food web; dead matter and faecal pellets sink as marine snow and are decomposed at depth or buried, so carbon leaves the surface (Merit).

8. Using equations, explain how dissolving CO_2 lowers the pH of seawater.
   $CO_2 + H_2O \rightleftharpoons H_2CO_3$, then $H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$ and $HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$. More CO_2 shifts the equilibria right, raising $[H^+]$, so pH = −log$[H^+]$ falls (Merit for two equations with charges and an explanation).

9. Explain why young pāua may grow weaker shells as the ocean takes up more CO_2.
   The extra H^+ combines with carbonate, $H^+ + CO_3^{2-} \rightarrow HCO_3^-$, so fewer carbonate ions are available for $Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$. Pāua larvae and juveniles must spend more energy building shell, and in cold water, already low in carbonate, the shell may grow thinner or even dissolve, reducing survival (Excellence links uptake, equilibrium shift, carbonate loss and the effect on the organism).

10. Correct this statement: "Ocean acidification means the sea is now an acid with a pH below 7."
    The sea is still basic (about pH 8.1); acidification means its pH is falling towards acidic.

11. Correct this statement: "A fall of 0.1 in pH is too small to matter."
    pH is logarithmic: a 0.1 fall means about 26% more hydrogen ions.

12. Correct this statement: "Extra CO_2 gives shellfish more carbonate to build shells with."
    The extra H^+ reacts with carbonate to form hydrogencarbonate, so carbonate ions decrease.

13. Correct this statement: "Warm tropical water absorbs the most CO_2 because it has the most plankton."
    Cold water dissolves more CO_2, and cold, windy, sinking regions like the Southern Ocean take up the most.

Answer key (for parents and tutors)

1. A swell has a period of 10 s in deep water. Find its speed.
   $v = gT \div 2\pi = 9.8 \times 10 \div 6.283 = 15.6\ m\ s^{-1}$.
2. Find its wavelength in deep water.
   $\lambda = vT = 15.6 \times 10 = 156\ m$.
3. Find its speed in water 5.0 m deep.
   $v = \sqrt{(9.8 \times 5.0)} = \sqrt{49} = 7.0\ m\ s^{-1}$.
4. A wave's height grows from 1.0 m to 2.0 m. By what factor does its energy increase?
   Energy $\propto$ height^2, so $2.0^2 \div 1.0^2 = 4$ times.
5. High tide at Tauranga is at 3:40 am. About when is the next high tide?
   Add about 12 h 25 min: about 4:05 pm.
6. During an El Niño, which way does warm surface water move, and what happens to upwelling off Peru?
   It moves east, back across the Pacific, and upwelling of cold, nutrient-rich water off Peru weakens.
7. Describe what happens to the trade winds and the warm water of the equatorial Pacific during an El Niño.
   The trade winds weaken or reverse, and the warm water piled up in the western Pacific spreads back east towards South America (Achieved).
8. Explain how these changes affect the Walker circulation and rainfall across the Pacific.
   With warm water in the central and eastern Pacific, rising air and heavy rain shift east, so Indonesia and northern Australia become drier and Peru wetter; the Walker loop weakens, which weakens the trades further, a positive feedback (Merit).
9. Explain why Hawke's Bay is more likely to be dry during an El Niño summer.
   El Niño brings more frequent south-westerly winds over New Zealand. Air reaching Hawke's Bay from the south-west has crossed the ranges and dropped its moisture on the western side, then descends and warms on the eastern side (a rain shadow and föhn effect), so the east is drier and windier, increasing drought risk (Merit for wind direction linked to rain shadow).
10. Explain why the farmer should treat the El Niño as a raised risk, not a certainty.
    ENSO explains less than a quarter of the variation in New Zealand's seasonal climate; the Southern Annular Mode, local weather systems and sea temperatures around New Zealand also matter, so some El Niño summers are not dry in Hawke's Bay (Excellence links the Pacific changes to New Zealand's winds and weighs the uncertainty).
11. Correct this statement: "Waves carry water across the ocean to the beach."
    Water particles move in circles and stay roughly in place; waves transfer energy.
12. Correct this statement: "El Niño means the trade winds get stronger."
    The trades weaken in an El Niño; they strengthen in a La Niña.
13. Correct this statement: "Doubling a wave's height doubles its energy."
    Energy is proportional to height squared, so doubling the height gives four times the energy.
14. Correct this statement: "Spring tides happen only in spring."
    Spring tides come twice a month, at new and full Moon, when the Sun and Moon line up.

Answer key (for parents and tutors)

1. Use p = 1013 e^(−h ÷ 8.0) to find the pressure at 5.5 km.
   p = 1013 × e^(−0.6875) = 1013 × 0.503 = 509 hPa, about half.
2. On a day when it is 15 °C at the ground, estimate the temperature 4.0 km up, using 6.5 °C per kilometre.
   15 − 6.5 × 4.0 = 15 − 26 = −11 °C.
3. In which layer does temperature rise with height because ozone absorbs ultraviolet light?
   The stratosphere.
4. Why is nitrogen not a greenhouse gas?
   N_2 is two identical atoms; its vibration does not change how charge is spread across it, so it cannot absorb infrared.
5. If Earth's albedo rose from 0.30 to 0.32, how much energy per square metre would be absorbed, taking 340 W m^{-2} arriving?
   340 × (1 − 0.32) = 340 × 0.68 = 231 W m^{-2}, down from 238 W m^{-2}.
6. Describe how ozone forms in the stratosphere and how it absorbs ultraviolet light.
   Ultraviolet light splits O_2 into oxygen atoms, which join other O_2 molecules to make O_3. Ozone absorbs UV and splits into O_2 and O, which recombine, so the cycle repeats and the UV energy becomes heat (Achieved).
7. Explain why temperature increases with height in the stratosphere.
   UV arrives from above and is absorbed as it passes down through the ozone, so most heating happens high in the stratosphere; with heat added at the top and none from below, temperature rises with height (Merit).
8. Explain why New Zealand's summer UV is higher than at the same latitude in the Northern Hemisphere.
   The Earth is closest to the Sun in early January, during the southern summer, so about 7% more sunlight arrives than in the northern summer; the air over New Zealand has fewer pollution aerosols to scatter and absorb UV; and southern summer ozone is slightly lower (Merit for two linked reasons).
9. Explain how clouds and aerosols change the amount of UV reaching the ground.
   Thick cloud reflects and absorbs much of the UV, cutting it sharply, while broken cloud can reflect extra UV onto the ground near cloud edges; aerosols such as smoke and sulfate scatter and absorb UV, so clean air lets more through. Combining Earth's orbit, clean air and the ozone layer explains New Zealand's high UV, and why the UV Index can be high even on a cool or partly cloudy day (Excellence).
10. Correct this statement: "The thermosphere is 1500 °C, so it would burn a spacecraft."
    Its particles are fast but so few that little heat is transferred; spacecraft orbit in it without burning.
11. Correct this statement: "The greenhouse effect is caused by the ozone hole letting heat in."
    Greenhouse gases absorb outgoing infrared; the ozone hole lets more UV reach the ground, a separate problem.
12. Correct this statement: "Nitrogen is the main greenhouse gas because there is most of it."
    N_2 and O_2 do not absorb infrared; water vapour and CO_2 do, despite their small amounts.
13. Correct this statement: "Pressure falls by the same amount for every kilometre you climb."
    Pressure falls exponentially, halving about every 5.5 km, so the drop per kilometre gets smaller with height.

Answer key (for parents and tutors)

1. Find the Coriolis parameter f at 30° S.
   $f = 2 \times 7.29 \times 10^{-5} \times \sin 30° = 2 \times 7.29 \times 10^{-5} \times 0.5 = 7.29 \times 10^{-5}\ s^{-1}$.
2. Which wind belt is New Zealand in, and which direction does it blow from?
   The westerlies, blowing from the west (north-west to south-west).
3. Which way does air circulate around a low in the Southern Hemisphere?
   Clockwise.
4. Air at 20 °C at sea level crosses a 1500 m range, with cloud forming from 500 m. Using 9.8 °C per km dry and 6.0 °C per km in cloud, find its temperature back at sea level on the other side.
   Up to 500 m: 20 − 9.8 × 0.5 = 15.1 °C; 500 to 1500 m in cloud: 15.1 − 6.0 = 9.1 °C; down 1500 m dry: 9.1 + 9.8 × 1.5 = 23.8 °C.
5. Why are winds light in the doldrums?
   The air there is mostly rising, not moving sideways, and the Coriolis effect is almost zero, so there is little horizontal wind.
6. Describe where air rises and sinks in the Hadley cell.
   Air rises at the equator (the ITCZ), flows polewards high up, and sinks at about 30° (Achieved).
7. Explain why the region near 30° S is so dry.
   The air that sinks at 30° has already lost its moisture as rain in the tropics; as it sinks it is compressed and warms, so its relative humidity falls, clouds evaporate and rain cannot form, giving the high-pressure subtropical desert belt (Merit).
8. Explain why the surface trade winds in the Southern Hemisphere blow from the south-east.
   At the surface, air flows from the subtropical high at 30° S back towards the equatorial low, so it starts moving north. The Coriolis effect deflects it to the left in the Southern Hemisphere, turning it towards the north-west, so it blows from the south-east (Merit).
9. Explain why northern New Zealand often has long settled spells in summer.
   In the southern summer the Sun is further south, so the whole circulation, including the subtropical high-pressure belt, shifts south. Large slow-moving anticyclones then often sit over northern New Zealand; their sinking air suppresses cloud and they block the westerly fronts, giving long dry, settled spells (Excellence links heating, cell structure, seasonal shift and the weather).
10. Correct this statement: "The westerlies blow towards the west."
    Winds are named from where they come: westerlies blow from the west towards the east.
11. Correct this statement: "In New Zealand air goes clockwise around a high."
    In the Southern Hemisphere air goes anticlockwise around a high and clockwise around a low.
12. Correct this statement: "Air sinks at 30° because it has reached the edge of the cell."
    It sinks because it has cooled aloft and the Coriolis effect has turned it so it piles up and converges.
13. Correct this statement: "The nor'wester is hot because it comes from Australia."
    It is warm because it dropped its moisture on the West Coast and was compressed and warmed as it descended.

Answer key (for parents and tutors)

1. 25 mm of rain falls on 1.0 km². How much latent heat was released when it condensed? Use $L = 2.26 \times 10^6$ J kg^{-1}.
   Mass = 0.025 m × 1.0 × 10^6 m² × 1000 kg m^{-3} = 2.5 × 10^7 kg; Q = 2.5 × 10^7 × 2.26 × 10^6 = 5.7 × 10^{13} J.

2. Using the CO_2 table, find the average rate of rise from 2010 to 2020.
   (414.2 − 390.1) ÷ 10 = 24.1 ÷ 10 = 2.4 ppm a year.

3. New Zealand's mean temperature in 2021 was 13.56 °C. How far above the 1981 to 2010 average of 12.61 °C was it?
   13.56 − 12.61 = 0.95 °C.

4. Why does SO_2 that reaches the stratosphere affect climate for longer than SO_2 that stays in the troposphere?
   There is no rain in the stratosphere to wash the sulfate aerosol out, so it stays for one to three years and spreads worldwide; in the troposphere rain removes it within about a week or two.

5. Why does the CO_2 record rise and fall a little every year?
   Plants in the Northern Hemisphere, which has most of the land, take in CO_2 during the northern summer and release it as they decay in winter.

6. Describe what happened in the troposphere close to the volcano.
   Ash and gas fell out of the troposphere near the volcano within days, darkening the sky and cooling it locally; SO_2 there formed sulfate that rain washed out as acid rain (Achieved).

7. Explain how the SO_2 in the stratosphere cooled the Earth's surface.
   In the stratosphere the SO_2 reacted with water vapour to form tiny sulfuric acid droplets. These reflect and scatter incoming short-wave sunlight back to space, so less reaches the surface and it cools; they also absorb some radiation, warming the stratosphere (Merit).

8. Explain why the cooling was felt around the world, including in New Zealand.
   The stratosphere has no weather to remove the droplets, and stratospheric winds carried the aerosol around the globe within months and spread it into both hemispheres, so the reduction in sunlight was global, reaching New Zealand's skies with vivid sunsets (Merit).

9. Explain why the cooling lasted only about two years.
   The droplets slowly grow and settle out of the stratosphere over one to three years, so as the aerosol layer thinned, sunlight returned to normal; meanwhile the greenhouse gases that drive the long-term warming were unchanged, so warming resumed (Excellence links injection height, aerosol formation, global spread, residence time and the long-term trend).

10. Correct this statement: "Volcanic ash in the stratosphere is what cools the climate for years."
    Ash falls out within weeks; the long cooling comes from sulfate aerosol droplets made from SO_2.

11. Correct this statement: "Last winter was cold, so the climate is not warming."
    Climate is a 30-year average; one season is weather, and trends need long records.

12. Correct this statement: "Evaporation cools the air because the water takes heat from it."
    Evaporation cools the surface it leaves; the latent heat is released into the air when the vapour condenses.

13. Correct this statement: "The yearly wiggle in CO_2 is caused by people burning more fuel in winter."
    It comes from Northern Hemisphere plants taking in CO_2 in their summer and releasing it in winter.

Answer key (for parents and tutors)

1. A star of radius 7.0×10^5 km dims by 0.25% during a transit. Find the planet's radius.
   $R_p \div R_s = \sqrt{0.0025} = 0.05$, so $R_p = 0.05 \times 7.0 \times 10^5 = 3.5 \times 10^4$ km.
2. A planet orbits a Sun-like star at 4.0 AU. What is its orbital period?
   $T^2 = 4.0^3 = 64$, so $T = 8.0$ years.
3. A star has a parallax of 0.10 arcseconds. How far away is it in parsecs and light years?
   $d = 1 \div 0.10 = 10$ pc $= 10 \times 3.26 = 32.6$ light years.
4. If a planet's radius were doubled, by what factor would its transit depth change?
   Depth $\propto R_p^2$, so $2^2 = 4$ times deeper.
5. For a report on an exoplanet's radius, which is more reliable: the NASA Exoplanet Archive or a news article, and why?
   The archive: it gives the measured value with its uncertainty and the peer-reviewed paper it came from, while a news article may round, simplify or misreport it.
6. Correct this statement: "A 1% dip means the planet is 1% of the star's radius."
   The dip is the ratio of areas, so $R_p \div R_s = \sqrt{0.01} = 0.1$, a tenth of the star's radius.
7. Correct this statement: "Kepler's third law: $T = a^3$."
   It is $T^2 = a^3$ (in years and AU for the Sun), so $T = a^{1.5}$.
8. Correct this statement: "A bigger parallax means a star is further away."
   $d = 1 \div p$, so a bigger parallax means a closer star.
9. Correct this statement: "I used five websites, so my information is reliable."
   Reliability comes from the kind of source (primary data, peer review, uncertainties), not the number of websites.

Answer key (for parents and tutors)

1. Three timings of 10 oscillations are 8.42 s, 8.50 s and 8.46 s. Find T with its uncertainty.
   Mean 10T = (8.42 + 8.50 + 8.46) ÷ 3 = 8.46 s, uncertainty (8.50 − 8.42) ÷ 2 = 0.04 s, so T = 0.846 ± 0.004 s.
2. Using T = 0.846 ± 0.004 s, find T^2 with its absolute uncertainty.
   $T^2 = 0.846^2 = 0.716\ s^2$; percentage uncertainty 2 × (0.004 ÷ 0.846) = 0.95%, so $T^2 = 0.716 \pm 0.007\ s^2$.
3. Theory says $f = (1/2L)\sqrt{(F/\mu)}$, with tension F varied. What should you plot to get a straight line?
   f against √F, a straight line through the origin with gradient $1/(2L\sqrt{\mu})$.
4. A graph of T^2 against m has gradient 2.47 $s^2\ kg^{-1}$. Find the spring constant k.
   gradient = $4\pi^2/k$, so $k = 4\pi^2 \div 2.47 = 39.48 \div 2.47 = 16.0\ N\ m^{-1}$.
5. The steepest and shallowest lines on a graph have gradients 2.55 and 2.40 $s^2\ kg^{-1}$. What is the uncertainty in the gradient?
   (2.55 − 2.40) ÷ 2 = ± 0.08 $s^2\ kg^{-1}$ (0.075 rounded).
6. Correct this statement: "I timed one oscillation five times and averaged it, so my reaction time does not matter."
   Time 10 or more oscillations each go, so the same reaction error is a tenth of the size per period.
7. Correct this statement: "T has a 1.3% uncertainty, so T^2 has a 1.3% uncertainty too."
   Squaring doubles the percentage uncertainty: 2 × 1.27% = 2.5% for T^2.
8. Correct this statement: "The theory has no constant term, so I forced my best-fit line through the origin."
   Draw the line the data give; an intercept is evidence you discuss, and forcing it changes the gradient.
9. Correct this statement: "My value of k is 20.0 and the other method gave 20.2, so they are different."
   Compare using uncertainties: 20.2 lies inside 20.0 ± 0.8 $N\ m^{-1}$, so the values agree.

Answer key (for parents and tutors)

1. Find the critical angle for light going from glass (n = 1.50) into water (n = 1.33).
   $\sin\theta c = 1.33 \div 1.50 = 0.8867$, so $\theta c = 62.5°$.

2. Find the speed of light in glass with n = 1.50.
   $v = c \div n = 3.00 \times 10^{8} \div 1.50 = 2.00 \times 10^{8}$ m s^{-1}.

3. Find the energy of a photon of wavelength 1310 nm. Use h = 6.63 × 10^{-34} J s.
   $E = hc/\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) \div (1310 \times 10^{-9}) = 1.52 \times 10^{-19}$ J.

4. Explain why a fibre's cladding must have a lower refractive index than its core.
   Total internal reflection only happens when light meets a boundary into a lower refractive index at more than the critical angle, so a lower-index cladding keeps the light in the core.

5. How long does light take to travel 25.0 km along a fibre core with n = 1.468?
   $v = 3.00 \times 10^{8} \div 1.468 = 2.044 \times 10^{8}$ m s^{-1}, $t = 25.0 \times 10^{3} \div 2.044 \times 10^{8} = 1.22 \times 10^{-4}$ s, which is 122 µs.

6. Correct this statement: "Total internal reflection happens when light goes from the cladding into the core."
   It only happens going from higher index to lower, so from the core into the cladding.

7. Correct this statement: "The critical angle is measured from the surface of the boundary."
   Angles in Snell's law are measured from the normal, so $\theta c = 84.8°$ means the ray almost grazes the boundary.

8. Correct this statement: "Light travels through the fibre at 3.00 × 10^{8} m s^{-1}."
   That is its speed in a vacuum; in the core it is $c \div n = 2.04 \times 10^{8}$ m s^{-1}.

9. Correct this statement: "My report lists refraction, photons and dispersion, so it is comprehensive."
   Excellence needs the ideas linked: say how each one depends on or affects the others in the device.

Answer key (for parents and tutors)

1. Two speakers in phase emit sound of wavelength 0.40 m. At point P the path difference is 1.00 m. Is P loud or quiet?
   1.00 ÷ 0.40 = 2.5 wavelengths, a half number, so P is quiet (destructive interference).
2. Light of wavelength 600 nm passes through slits 0.300 mm apart onto a screen 1.50 m away. Find the fringe spacing.
   $\Delta x = \lambda L \div d = (600 \times 10^{-9} \times 1.50) \div (0.300 \times 10^{-3}) = 3.00 \times 10^{-3}$ m = 3.00 mm.
3. Find the slit spacing d of a grating with 300 lines per mm.
   $d = 1 \div (300 \times 10^{3}) = 3.33 \times 10^{-6}$ m.
4. Yellow light of 589 nm shines on that grating. Find the angle of the second-order maximum.
   $\sin\theta = 2 \times 589 \times 10^{-9} \div 3.333 \times 10^{-6} = 0.3534$, $\theta = 20.7°$.
5. What is the highest order maximum that grating gives for 589 nm light?
   $d \div \lambda = 3.333 \times 10^{-6} \div 589 \times 10^{-9} = 5.66$, so the 5th order (n = 6 would need sin θ greater than 1).
6. Calculate the angle of the first-order maximum.
   $d = 1 \div (500 \times 10^{3}) = 2.00 \times 10^{-6}$ m; $\sin\theta = 635 \times 10^{-9} \div 2.00 \times 10^{-6} = 0.3175$, $\theta = 18.5°$ (Achieved).
7. Calculate the distance on the wall from the central maximum to the first-order maximum.
   The angle is too large for $x = n\lambda L \div d$, so $x = L \tan\theta = 1.50 \times \tan 18.5° = 1.50 \times 0.3348 = 0.502$ m (Merit; Achieved if the small-angle formula gives 0.476 m).
8. Explain why the first-order maximum is bright.
   At that angle light from each slit travels exactly one wavelength further than light from the slit next to it, so all the waves arrive in phase and superpose constructively, and because so many slits add together the maximum is bright (Merit for path difference and phase, Excellence for linking to superposition from many slits).
9. Aroha changes to a violet laser of wavelength 405 nm. Describe and explain how the pattern changes, including how many maxima there are.
   With a shorter wavelength, $\sin\theta = n\lambda \div d$ is smaller, so every maximum moves closer to the centre. The highest order rises: for red $d \div \lambda = 3.15$, so 3 orders and 7 maxima; for violet $d \div \lambda = 4.94$, so 4 orders and 9 maxima (Excellence for the explanation and both counts).
10. Correct this statement: "For a grating, $\sin\theta = x/L$, so I used $n\lambda = dx/L$ at 40°."
    x/L is only a small-angle approximation; for a grating find θ from $n\lambda = d \sin\theta$, then $x = L \tan\theta$ if needed.
11. Correct this statement: "The grating has 600 lines per mm, so d = 600 mm."
    d is the gap between lines: $1 \div 600$ mm = 1.67×10^{-3} mm = 1.67×10^{-6} m.
12. Correct this statement: "$d \div \lambda = 3.13$, so there are 3 maxima."
    There are 3 orders on each side plus the central maximum: 7 in all.
13. Correct this statement: "Dark fringes are where no light reaches the screen from the slits."
    Light from both slits arrives there, but 180° out of phase, so the waves cancel.

Answer key (for parents and tutors)

1. A string 0.500 m long carries waves at 200 m s^{-1}. Find its fundamental frequency.
   $f_1 = v \div 2L = 200 \div 1.00 = 200$ Hz.
2. Find the wavelength of the 4th harmonic on that string.
   $\lambda = 2L \div n = 1.00 \div 4 = 0.250$ m.
3. A pipe 0.250 m long is closed at one end. Using v = 340 m s^{-1}, find the next frequency it can play above its fundamental.
   $f_1 = v \div 4L = 340 \div 1.00 = 340$ Hz; the next harmonic is the 3rd, $3 \times 340 = 1020$ Hz.
4. Two tuning forks of 256 Hz and 260 Hz are struck together. Find the beat frequency.
   f_beat = 260 − 256 = 4 Hz.
5. The tension in a string is quadrupled. What happens to its fundamental frequency?
   $v = \sqrt{(T/\mu)}$ doubles when T is multiplied by 4, and $f = v/2L$, so the fundamental doubles.
6. Calculate the fundamental frequency of a tube 0.180 m long.
   $f_1 = v \div 4L = 343 \div 0.720 = 476$ Hz (Achieved).
7. Describe the displacement pattern of the next harmonic this tube can produce and calculate its frequency.
   A node at the closed bottom and an antinode at the open top, with one more node and antinode between: $L = 3\lambda/4$. $f_3 = 3 \times 476.4 = 1429$ Hz, about 1430 Hz (Merit for the pattern and frequency).
8. He plays the tube next to a 480 Hz tuning fork. Calculate the beat frequency and explain how the beats form.
   f_beat = 480 − 476.4 = 3.6 Hz. The two sounds drift in and out of phase; in phase they interfere constructively and the sound is loud, 180° out of phase they interfere destructively and it is quiet, so the loudness pulses 3.6 times a second (Merit for the explanation).
9. On a hot day the speed of sound rises to 349 m s^{-1}. Explain what happens to the tube's fundamental and to the beats with the fork.
   The tube length is fixed, so $\lambda = 4L = 0.720$ m stays the same; $f = v/\lambda$ rises to $349 \div 0.720 = 484.7$ Hz. It is now above the fork, so the beat frequency is 484.7 − 480 = 4.7 Hz: the beats first slowed and stopped as the note passed 480 Hz, then sped up again (Excellence for linking fixed λ, v and f to the beats).
10. Correct this statement: "Nodes on a string are one wavelength apart."
    Neighbouring nodes are $\lambda/2$ apart, so one loop is half a wavelength.
11. Correct this statement: "A closed pipe's next harmonic after f_1 is $2f_1$."
    Only odd harmonics fit a closed pipe, so the next one is $3f_1$.
12. Correct this statement: "Two notes of 256 Hz and 260 Hz give a beat frequency of 258 Hz."
    The beat frequency is the difference, 4 Hz; about 258 Hz is the pitch you hear.
13. Correct this statement: "Doubling the tension doubles the frequency."
    f is proportional to $v = \sqrt{(T/\mu)}$, so doubling T multiplies f by $\sqrt{2}$; quadrupling T doubles it.

Answer key (for parents and tutors)

1. A 600 Hz source moves at 20.0 m s^{-1} towards a stationary listener. Using v = 340 m s^{-1}, find the frequency heard.
   f' = 600 × 340 ÷ (340 − 20.0) = 204 000 ÷ 320 = 637.5 Hz, about 638 Hz.

2. The same source moves away from the listener at 20.0 m s^{-1}. Find the frequency heard.
   f' = 600 × 340 ÷ 360 = 566.7 Hz, about 567 Hz.

3. Find the wavelength of the sound in front of the source in question 1.
   λ' = (v − vs) ÷ f = 320 ÷ 600 = 0.533 m.

4. A galaxy's 486.1 nm hydrogen line is measured at 484.2 nm. Is it approaching or moving away, and how fast?
   Δλ = 484.2 − 486.1 = −1.9 nm, shorter, so blue shifted and approaching; v = 3.00 × 10^8 × 1.9 ÷ 486.1 = 1.2 × 10^6 m s^{-1} towards us.

5. A car drives in a circle around you at constant speed, sounding a 400 Hz horn. What frequency do you hear?
   The car's velocity is always across your line of sight, never towards or away, so there is no shift: you hear 400 Hz.

6. Calculate the frequency Mere hears.
   f' = 750 × 343 ÷ (343 − 22.0) = 257 250 ÷ 321 = 801.4 Hz, about 801 Hz (Achieved).

7. Explain why Mere hears a different frequency from the one the horn emits.
   The boat moves forward between emitting one wavefront and the next, so the wavefronts ahead are closer together and the wavelength reaching Mere is shorter; the speed of sound is set by the air and is unchanged, so by v = fλ she receives more waves each second and hears a higher frequency (Merit for two linked ideas, Excellence for wavelength, constant speed and v = fλ together).

8. The boat swerves past the jetty and travels directly away at the same speed. Calculate the frequency she now hears.
   f' = 750 × 343 ÷ (343 + 22.0) = 257 250 ÷ 365 = 704.8 Hz, about 705 Hz (Achieved).

9. An underwater microphone ahead of the boat picks up its 400 Hz engine note as 406.0 Hz while the boat approaches at 22.0 m s^{-1}. Calculate the speed of sound in the water.
   406.0 = 400 × v ÷ (v − 22.0), so 406.0v − 8932 = 400v, 6.0v = 8932, v = 1489 m s^{-1}, about 1490 m s^{-1} (Merit for the correct substitution, Excellence for the correct rearrangement and answer).

10. Correct this statement: "The source is approaching, so I used v + vs on the bottom."
    Approaching must raise the frequency, so the bottom is v − vs, which is smaller than v.

11. Correct this statement: "The siren itself gets higher as the ambulance speeds up."
    The source frequency is unchanged; only the wavelength reaching the observer, and so the frequency heard, changes.

12. Correct this statement: "The sound travels faster in front of the moving ambulance."
    The wave speed is set by the air; the source's speed changes the wavelength, not the wave speed.

13. Correct this statement: "At the moment the car passes me I hear the lowest pitch."
    At the closest point the car moves neither towards nor away, so you hear the true frequency; the lowest comes as it moves off.

Answer key (for parents and tutors)

1. A 4.0 kg mass sits at x = 0 and a 1.0 kg mass at x = 2.5 m. Where is the centre of mass?
   $x_{cm} = (4.0 \times 0 + 1.0 \times 2.5) \div 5.0 = 0.50$ m from the 4.0 kg mass.

2. A 0.0580 kg tennis ball hits a racquet at 20.0 m s^{-1} and returns straight back at 30.0 m s^{-1}. Contact lasts 4.00 ms. Find the average force on the ball.
   Taking the return direction as positive, $\Delta p = 0.0580 \times (30.0 - (-20.0)) = 0.0580 \times 50.0 = 2.90$ kg m s^{-1}; $F = 2.90 \div 0.00400 = 725$ N, in the direction the ball returns.

3. A 0.400 kg ball moving east at 5.00 m s^{-1} hits a 0.600 kg ball moving north at 2.50 m s^{-1}, and they stick together. Find their velocity.
   p east $= 0.400 \times 5.00 = 2.00$, p north $= 0.600 \times 2.50 = 1.50$ kg m s^{-1}; $p = \sqrt{(2.00^2 + 1.50^2)} = 2.50$ kg m s^{-1}; $v = 2.50 \div 1.00 = 2.50$ m s^{-1}; $\tan\theta = 1.50 \div 2.00$, $\theta = 36.9°$ north of east.

4. A 3.00 kg object at rest explodes into three 1.00 kg pieces. One goes east at 6.00 m s^{-1} and one north at 8.00 m s^{-1}. Find the velocity of the third piece.
   Total momentum stays zero, so the third piece has momentum equal and opposite to the sum of the other two: $\sqrt{(6.00^2 + 8.00^2)} = 10.0$ kg m s^{-1}, so $v = 10.0$ m s^{-1}; the other two add to a direction 53.1° north of east ($\tan\theta = 8.00 \div 6.00$), so the third piece moves at 10.0 m s^{-1} at 53.1° south of west.

5. Calculate the size of each player's momentum before the tackle.
   Sione: $95.0 \times 6.00 = 570$ kg m s^{-1}; Nikau: $110 \times 5.00 = 550$ kg m s^{-1} (Achieved for both).

6. Calculate the velocity of the two players just after the tackle. A vector diagram may help.
   Components with east and north positive: Sione (570, 0); Nikau ($-550\cos 60.0°$, $550\sin 60.0°$) = (−275, 476.3). Total (295, 476.3) kg m s^{-1}, size $\sqrt{(295^2 + 476.3^2)} = 560.3$ kg m s^{-1}; $v = 560.3 \div 205 = 2.73$ m s^{-1}; $\tan\theta = 476.3 \div 295$, $\theta = 58.2°$ north of east (Merit for the method with one slip, Excellence for the size and direction).

7. The tackle lasts 0.300 s. Calculate the size of the average force on Sione.
   Sione's velocity after is (1.439, 2.323) m s^{-1}, so $\Delta v = (1.439 - 6.00, 2.323) = (-4.561, 2.323)$; $\Delta p = 95.0 \times \sqrt{(4.561^2 + 2.323^2)} = 486.3$ kg m s^{-1}; $F = 486.3 \div 0.300 = 1620$ N (Excellence; Nikau's change in momentum has the same size, the other way).

8. Explain why momentum is conserved in the tackle but kinetic energy is not.
   During the tackle the forces between the players are an internal action and reaction pair, equal in size, opposite in direction and acting for the same time, so the impulses cancel and the total momentum is unchanged. Kinetic energy falls from 3085 J to $\frac{1}{2} \times 205 \times 2.73^2 = 766$ J because the players deform and grip, so work is done converting kinetic energy into heat and sound; this is an inelastic collision (Excellence links the internal forces to momentum and the energy change to the inelastic collision).

9. Correct this statement: "Total momentum = 18 000 + 21 000 = 39 000 kg m s^{-1} for the two cars."
   Momenta at right angles add as vectors: $\sqrt{(18\,000^2 + 21\,000^2)} = 27\,700$ kg m s^{-1}.

10. Correct this statement: "The ball hits and leaves at 12.0 m s^{-1}, so its momentum did not change and there was no impulse."
    The speed is the same but the direction changed, so $\Delta p = p_{final} - p_{initial}$ is not zero.

11. Correct this statement: "Momentum is conserved, so kinetic energy must be conserved as well."
    Kinetic energy is conserved only in elastic collisions; momentum is conserved in every collision without an external force.

12. Correct this statement: "The angle of 49.4° is just given as the answer, with no reference direction."
    Give a direction against something fixed, such as 49.4° north of east or measured from car A's original path.

Answer key (for parents and tutors)

1. A 0.050 kg ball on a string moves in a horizontal circle of radius 0.40 m, taking 0.50 s per revolution. Find the tension, ignoring gravity.
   $v = 2\pi r \div T = 2\pi \times 0.40 \div 0.50 = 5.03\ m\ s^{-1}$; $T = mv^2 \div r = 0.050 \times 5.03^2 \div 0.40 = 3.16\ N$.

2. A bend of radius 120 m is banked at 12.0°. At what speed is no friction needed?
   $\tan\theta = v^2 \div (rg)$, so $v = \sqrt{(rg \tan\theta)} = \sqrt{(120 \times 9.81 \times \tan 12.0°)} = \sqrt{250.2} = 15.8\ m\ s^{-1}$.

3. A roller coaster loop has radius 12.0 m at the top. What is the slowest the car can go at the top and still follow the track?
   At the slowest speed the track pushes with zero force and weight alone supplies the centripetal force: $v = \sqrt{(gr)} = \sqrt{(9.81 \times 12.0)} = 10.8\ m\ s^{-1}$.

4. An 80.0 kg astronaut weighs 785 N on the Earth's surface. What is the gravitational force on her one Earth radius above the surface?
   One Earth radius above the surface she is twice as far from the centre, so the force is a quarter: $785 \div 4 = 196\ N$.

5. Show that the gravitational field strength at the satellite's height is 7.97 N kg^{-1}.
   $r = 6.37 \times 10^6 + 7.00 \times 10^5 = 7.07 \times 10^6$ m; $g = GM \div r^2 = 6.67 \times 10^{-11} \times 5.97 \times 10^{24} \div (7.07 \times 10^6)^2 = 7.97\ N\ kg^{-1}$ (Achieved).

6. Calculate the satellite's orbital speed.
   Gravity supplies the centripetal force, so $v^2 = GM \div r$, or $v = \sqrt{(gr)} = \sqrt{(7.966 \times 7.07 \times 10^6)} = 7.50 \times 10^3\ m\ s^{-1}$ (Merit).

7. Calculate its orbital period in minutes.
   $T = 2\pi r \div v = 2\pi \times 7.07 \times 10^6 \div 7505 = 5919$ s, which is 98.7 minutes (Excellence for the full chain with the radius from Earth's centre).

8. Explain why the satellite keeps a constant speed without using its engines, even though a force acts on it the whole time.
   The only force is gravity, pointing to the Earth's centre, which is at right angles to the velocity at every point of a circular orbit. A force at right angles to the motion does no work, so the kinetic energy and speed do not change; the force only changes the direction, which gives the centripetal acceleration that keeps the satellite on the circle. With no air resistance at this height, nothing removes energy, so no engine is needed (Excellence links the force direction, work and the circular path).

9. Correct this statement: "The free-body diagram shows weight, tension and a centripetal force."
   Centripetal force is the resultant of the real forces, so draw only weight and tension; their sum points to the centre.

10. Correct this statement: "For a satellite 700 km up, $F = GMm \div (7.00 \times 10^5)^2$."
    r is measured from Earth's centre: $r = 6.37 \times 10^6 + 7.00 \times 10^5 = 7.07 \times 10^6$ m.

11. Correct this statement: "Astronauts in orbit are weightless because there is no gravity up there."
    At the height of the International Space Station, about 400 km up, gravity is still about 90% of its surface value; they are in free fall with their craft, so nothing pushes on them.

12. Correct this statement: "A heavier satellite must go faster to stay in the same orbit."
    The satellite's mass cancels in $GMm \div r^2 = mv^2 \div r$, so every satellite at radius r has the same speed.

Answer key (for parents and tutors)

1. A wind turbine turns at 15.0 revolutions per minute. Find its angular velocity and the speed of a blade tip 40.0 m from the hub.
   $\omega = 15.0 \times 2\pi \div 60 = 1.571$ rad s^{-1}, about 1.57 rad s^{-1}; $v = r\omega = 40.0 \times 1.571 = 62.8$ m s^{-1}.

2. A fan spinning at 25.0 rad s^{-1} slows uniformly to rest in 10.0 s. Find its angular acceleration and how many turns it makes.
   $\alpha = (0 - 25.0) \div 10.0 = -2.50$ rad s^{-2}; $\theta = \frac{1}{2}(25.0 + 0) \times 10.0 = 125$ rad, and $125 \div 2\pi = 19.9$ turns.

3. A net torque of 0.900 N m acts on a wheel with rotational inertia 0.0450 kg m^2. Find its angular acceleration.
   $\alpha = \tau \div I = 0.900 \div 0.0450 = 20.0$ rad s^{-2}.

4. A skater spinning at 3.00 rad s^{-1} changes her rotational inertia from 4.00 kg m^2 to 1.60 kg m^2. Find her new angular velocity and her rotational kinetic energy before and after.
   $\omega f = 4.00 \times 3.00 \div 1.60 = 7.50$ rad s^{-1}; Ek before $= \frac{1}{2} \times 4.00 \times 3.00^2 = 18.0$ J, after $= \frac{1}{2} \times 1.60 \times 7.50^2 = 45.0$ J.

5. Calculate the net torque on the wheel while it speeds up.
   $\alpha = 12.0 \div 3.00 = 4.00$ rad s^{-2}; $\tau = I\alpha = 0.850 \times 4.00 = 3.40$ N m (Achieved).

6. Calculate how many turns the wheel makes in those 3.00 s.
   $\theta = \frac{1}{2}(0 + 12.0) \times 3.00 = 18.0$ rad, and $18.0 \div 2\pi = 2.86$ turns (Achieved).

7. With the motor off and the wheel spinning freely at 12.0 rad s^{-1}, the potter drops a 4.00 kg disc of clay, radius 0.120 m, centrally onto it. The clay's rotational inertia is $\frac{1}{2}mr^2$. Calculate the new angular velocity.
   $I_clay = \frac{1}{2} \times 4.00 \times 0.120^2 = 0.0288$ kg m^2; with no external torque, $0.850 \times 12.0 = (0.850 + 0.0288) \times \omega f$, so $\omega f = 10.2 \div 0.8788 = 11.6$ rad s^{-1} (Merit for the method, Excellence with the clay's I included).

8. Explain why the rotational kinetic energy of the system decreases when the clay lands, even though angular momentum is conserved.
   Ek(rot) before $= \frac{1}{2} \times 0.850 \times 12.0^2 = 61.2$ J; after $= \frac{1}{2} \times 0.8788 \times 11.6^2 = 59.2$ J. When the clay lands it is not spinning, so the wheel's surface slides under it at first; friction between them gives the clay a torque that speeds it up and an equal and opposite torque that slows the wheel. These internal torques cancel, so angular momentum is conserved, but the sliding friction turns about 2.0 J of kinetic energy into heat, like an inelastic collision (Excellence links the internal torques to conservation of L and the friction to the energy loss).

9. Correct this statement: "1200 rpm is put straight into $\omega f = \omega i + \alpha t$ as $\omega = 1200$."
   Convert to rad s^{-1} first: $1200 \times 2\pi \div 60 = 125.7$ rad s^{-1}.

10. Correct this statement: "Angular momentum is conserved, so rotational kinetic energy is conserved too."
    L is conserved with no external torque, but Ek(rot) changes when I changes; pulling in raises it, a lump landing on a turntable lowers it.

11. Correct this statement: "The torque is F × r, using the distance to where the force acts, even when the force is at an angle."
    Use the perpendicular distance from the axis to the line of the force, or the force component at right angles to r.

12. Correct this statement: "The calculator is in degree mode for the trig in a rotation problem."
    Angular quantities are in radians, so set the calculator to radians for sin ωt and similar.

Answer key (for parents and tutors)

1. Find the period of a simple pendulum 0.800 m long.
   $T = 2\pi\sqrt{(0.800 \div 9.81)} = 1.79$ s.

2. A 0.500 kg mass hangs on a spring of stiffness 20.0 N m^{-1}. Find the period.
   $T = 2\pi\sqrt{(0.500 \div 20.0)} = 0.993$ s.

3. An object oscillates in SHM with amplitude 5.00 cm and period 0.400 s. Find its maximum speed and maximum acceleration.
   $\omega = 2\pi \div 0.400 = 15.71$ rad s^{-1}; $v_{max} = A\omega = 0.0500 \times 15.71 = 0.785$ m s^{-1}; $a_{max} = A\omega^2 = 0.0500 \times 15.71^2 = 12.3$ m s^{-2}.

4. A 0.300 kg mass on a spring of stiffness 120 N m^{-1} oscillates with amplitude 0.0500 m. Find the total energy and the speed when y = 0.0300 m.
   $E = \frac{1}{2}kA^2 = \frac{1}{2} \times 120 \times 0.0500^2 = 0.150$ J; $\omega = \sqrt{(120 \div 0.300)} = 20.0$ rad s^{-1}, so $v = \omega\sqrt{(A^2 - y^2)} = 20.0 \times \sqrt{(0.0500^2 - 0.0300^2)} = 20.0 \times 0.0400 = 0.800$ m s^{-1}.

5. Show that the angular frequency of the motion is 12.6 rad s^{-1}.
   $\omega = \sqrt{(k \div m)} = \sqrt{(40.0 \div 0.250)} = \sqrt{160} = 12.65$ rad s^{-1}, which is 12.6 rad s^{-1} (Achieved).

6. Calculate the maximum speed and the maximum acceleration of the mass.
   $v_{max} = A\omega = 0.0600 \times 12.65 = 0.759$ m s^{-1}; $a_{max} = A\omega^2 = 0.0600 \times 160 = 9.60$ m s^{-2} (Achieved for one, Merit for both).

7. Calculate the time after release when the mass first reaches 2.00 cm above equilibrium. A reference circle may help.
   Taking up as positive, $y = -0.0600 \cos \omega t$; at $y = +0.0200$, $\cos \omega t = -0.333$, so $\omega t = 1.911$ rad and $t = 1.911 \div 12.65 = 0.151$ s. On the reference circle the phasor turns 90° to equilibrium and then a further $\sin^{-1}(0.0200 \div 0.0600) = 19.5°$, 109.5° in all (Merit for the method with one error, Excellence for 0.151 s).

8. The top of the spring is then moved up and down by a hand at a frequency of 2.0 Hz. Explain, using forces and energy, why the mass oscillates with a very large amplitude.
   The natural frequency is $f = 12.65 \div 2\pi = 2.01$ Hz, so the hand drives the system at its natural frequency. Each push from the hand is then in step with the motion, in the same direction as the velocity, so the driving force does positive work on every cycle. Energy is added faster than damping removes it, so the energy stored, $\frac{1}{2}kA^2$, builds up cycle after cycle and the amplitude grows very large until the energy lost per cycle equals the energy supplied: this is resonance (Excellence links the matched frequency, the in-step force and the energy balance).

9. Correct this statement: "$\cos^{-1}(-0.500)$ in degree mode gives 120, so $t = 120 \div 3.927 = 30.6$ s."
   ωt is in radians, so set the calculator to radians before any sin ωt or cos ωt.

10. Correct this statement: "The acceleration is zero at the extremes because the object stops there."
    The velocity is zero at the extremes, but the restoring force and acceleration are greatest there, $A\omega^2$.

11. Correct this statement: "Using $y = A \sin \omega t$ for a mass released from rest at the top."
    Choose the function from the start: from rest at +A use $y = A \cos \omega t$, from equilibrium use $y = A \sin \omega t$.

12. Correct this statement: "A pendulum with a heavier bob or a bigger swing has a longer period."
    $T = 2\pi\sqrt{(l \div g)}$ depends only on length and g, for small swings; mass and amplitude cancel.

Answer key (for parents and tutors)

1. Find the energy in joules of a 450 nm photon. Use $h = 6.63 \times 10^{-34}$ J s and $c = 3.00 \times 10^{8}$ m s^{-1}.
   $E = hc \div \lambda = 1.989 \times 10^{-25} \div 450 \times 10^{-9} = 4.42 \times 10^{-19}$ J.
2. Give that energy in electronvolts.
   $4.42 \times 10^{-19} \div 1.60 \times 10^{-19} = 2.76$ eV.
3. Those photons fall on a metal with a work function of 2.10 eV. Find the electrons' maximum kinetic energy in eV.
   Ek(max) = 2.76 − 2.10 = 0.66 eV.
4. An electron in hydrogen falls from n = 4 to n = 2. Find the photon energy in eV.
   $E_4 = -13.6 \div 16 = -0.85$ eV, $E_2 = -3.40$ eV, so $\Delta E = -0.85 - (-3.40) = 2.55$ eV (a blue-green line at 486 nm).
5. The deuterium nucleus has a mass defect of 0.002388 u. Find its binding energy in MeV, using 1 u = 931.5 MeV.
   $E = 0.002388 \times 931.5 = 2.22$ MeV.
6. Correct this statement: "Brighter light gives the photoelectrons more kinetic energy."
   Brightness changes the number of photons; each electron's maximum energy depends only on frequency, $Ek = hf - \varphi$.
7. Correct this statement: "$Ek = 6.63 \times 10^{-19} - 2.28 = 6.63 \times 10^{-19}$ J."
   Put both in the same unit first: 2.28 eV = 3.65×10^{-19} J, then subtract.
8. Correct this statement: "The electron drops from n = 3 to n = 2, so the photon has $13.6 \div 3 - 13.6 \div 2$ eV."
   Levels go as $1/n^2$: $E_3 - E_2 = -13.6/9 - (-13.6/4) = 1.89$ eV.
9. Correct this statement: "Fission releases energy because the nucleus has extra energy stored in it."
   The products have greater binding energy per nucleon, so less total mass; the missing mass becomes energy.

Answer key (for parents and tutors)

1. An AA cell of EMF 1.50 V and internal resistance 0.400 Ω is connected to a 2.60 Ω resistor. Find the current and the terminal voltage.
   $I = \varepsilon \div (R + r) = 1.50 \div 3.00 = 0.500$ A; $V = IR = 0.500 \times 2.60 = 1.30$ V (or $1.50 - 0.500 \times 0.400 = 1.30$ V).

2. A battery reads 9.00 V on open circuit and 8.40 V when it supplies 0.300 A. Find its internal resistance.
   Lost volts = 9.00 − 8.40 = 0.60 V, so $r = 0.60 \div 0.300 = 2.00\ \Omega$ (2.0 Ω).

3. Currents of 2.0 A and 0.5 A flow into a junction and 1.2 A flows out along one wire. What current flows in the only other wire, and which way?
   In = 2.5 A, so out = 2.5 A: the other wire carries $2.5 - 1.2 = 1.3$ A out of the junction.

4. An e-bike battery has an EMF of 36.0 V and internal resistance 0.150 Ω. Climbing a hill, the motor draws 12.0 A. Find the terminal voltage and the power wasted in the battery.
   $V = 36.0 - 12.0 \times 0.150 = 34.2$ V; $P = I^2r = 12.0^2 \times 0.150 = 21.6$ W.

5. Calculate the current in the pump and the terminal voltage of battery A.
   $I = 12.0 \div (4.00 + 0.200) = 2.857$ A, about 2.86 A; $V = 12.0 - 2.857 \times 0.200 = 11.4$ V (Achieved).

6. Explain why the terminal voltage is less than the EMF.
   Some of the energy each coulomb gains in the battery is turned into heat as it passes through the internal resistance; these lost volts, $Ir = 0.571$ V, are not available at the terminals, so $V = \varepsilon - Ir$ is less than ε (Merit).

7. An older battery B (EMF 11.4 V, internal resistance 0.300 Ω) is connected in parallel with A, positive to positive. Use Kirchhoff's laws to calculate the current through each battery.
   Let the terminal voltage be V and the currents out of the positive terminals be I_A and I_B. Loop through A: $12.0 - 0.200I_A = V$. Loop through B: $11.4 - 0.300I_B = V$. Junction: $I_A + I_B = V \div 4.00$. Substituting: $(12.0 - V) \div 0.200 + (11.4 - V) \div 0.300 = V \div 4.00$, so $98.0 = 8.5833V$ and $V = 11.4175$ V (11.42 V to 4 significant figures). Keeping the unrounded V, $I_A = (12.0 - 11.4175) \div 0.200 = 2.91$ A and $I_B = (11.4 - 11.4175) \div 0.300 = -0.0583$ A, with 2.85 A in the pump (Excellence for all three).

8. Explain what the sign of battery B's current tells you, and why connecting it this way wastes energy.
   I_B is negative, so the current flows into battery B's positive terminal: battery A is charging battery B as well as running the pump. Because B's EMF is lower than the terminal voltage, A pushes current backwards through it, and both internal resistances turn that extra current into heat, so A's energy is wasted rather than all reaching the pump (Excellence links the sign, the EMFs and the energy).

9. Correct this statement: "$I = \varepsilon \div R = 9.00 \div 3.50 = 2.57$ A, leaving out the battery."
   The internal resistance is in series with the circuit: $I = \varepsilon \div (R + r) = 9.00 \div 4.00 = 2.25$ A.

10. Correct this statement: "The EMF of the battery drops when a bigger current is drawn."
    The EMF stays the same; the terminal voltage $\varepsilon - Ir$ drops because the lost volts grow.

11. Correct this statement: "The answer for I_2 came out negative, so I must have made a mistake."
    A negative current means the real current flows opposite to the arrow you drew; keep the sign in the other equations.

12. Correct this statement: "In the loop equation every EMF and every IR term is added as positive."
    Go round in one direction: an EMF is negative if you cross it from + to −, and an IR term is negative if you go against the current.

Answer key (for parents and tutors)

1. Two parallel plates, each of area 0.0100 m², are 0.200 mm apart in air. Find the capacitance.
   $C = \varepsilon_0 A \div d = 8.85 \times 10^{-12} \times 0.0100 \div 2.00 \times 10^{-4} = 4.43 \times 10^{-10}$ F (443 pF).

2. Find the total capacitance of 6.0 µF and 3.0 µF in series, and in parallel.
   Series: $1 \div C = 1 \div 6.0 + 1 \div 3.0 = 0.50$, so C = 2.0 µF; parallel: 6.0 + 3.0 = 9.0 µF.

3. How much energy does a 10 µF capacitor store at 12 V?
   $E = \frac{1}{2}CV^2 = \frac{1}{2} \times 10 \times 10^{-6} \times 12^2 = 7.2 \times 10^{-4}$ J (0.72 mJ).

4. A 4.7 mF capacitor discharges through a 1.0 kΩ resistor. Find the time constant and roughly how long it takes to discharge fully.
   $\tau = RC = 1000 \times 4.7 \times 10^{-3} = 4.7$ s; it is effectively discharged after about $5\tau = 24$ s.

5. Calculate the charge and energy stored when the capacitor is full.
   $Q = CV = 220 \times 10^{-6} \times 330 = 0.0726$ C; $E = \frac{1}{2}CV^2 = \frac{1}{2} \times 220 \times 10^{-6} \times 330^2 = 12.0$ J (Achieved).

6. Calculate the time constant, the starting recharge current, and the current after one time constant.
   $\tau = RC = 1500 \times 220 \times 10^{-6} = 0.330$ s; $I_0 = 330 \div 1500 = 0.220$ A; after one τ, $I = 0.368 \times 0.220 = 0.0809$ A (Merit for all three).

7. Explain why the recharge current is largest at the start and falls to zero.
   At the start the capacitor is empty, so it has no voltage across it and the full 330 V is across the resistor, giving the biggest current. As charge builds up, the capacitor's voltage $V = Q \div C$ rises and opposes the supply, so the voltage across the resistor, $\varepsilon - V_C$, falls, and so does the current. When V_C reaches 330 V the resistor has no voltage and the current is zero (Excellence links the charge, the capacitor voltage and the resistor current).

8. A designer suggests two 220 µF capacitors charged from the same 330 V supply. Explain, with calculations, how much energy they store connected in parallel compared with in series across 330 V.
   In parallel the total is 440 µF at 330 V: $E = \frac{1}{2} \times 440 \times 10^{-6} \times 330^2 = 24.0$ J, double one capacitor. In series the total is 110 µF across 330 V, so each has only 165 V: $E = \frac{1}{2} \times 110 \times 10^{-6} \times 330^2 = 5.99$ J, half of one capacitor. Parallel stores four times as much as series because the voltage on each capacitor is not shared and E depends on V^2 (Excellence for the comparison with reasons).

9. Correct this statement: "6.0 µF and 3.0 µF in series make 9.0 µF."
   In series the reciprocals add: $1 \div C = 1 \div 6.0 + 1 \div 3.0$, so C = 2.0 µF; 9.0 µF is the parallel total.

10. Correct this statement: "τ = RC = 2.20 × 470 = 1034 s, with kΩ and µF left as they are."
    Use ohms and farads: $\tau = 2200\ \Omega \times 470 \times 10^{-6}$ F = 1.03 s.

11. Correct this statement: "After one time constant the capacitor is half charged."
    After one τ it reaches 63% of full charge; it is half charged at about 0.69τ.

12. Correct this statement: "When the capacitor is fully charged the current is at its maximum because the most charge is stored."
    Fully charged, the capacitor's voltage equals the supply's, the resistor has no voltage and the current is zero.

Answer key (for parents and tutors)

1. A 0.250 T field passes at right angles through a loop of area 0.0400 m². Find the flux.
   $\varphi = BA = 0.250 \times 0.0400 = 0.0100$ Wb.
2. That flux falls to zero in 0.100 s through a 500-turn coil. Find the average induced EMF.
   $\varepsilon = N\Delta\varphi \div \Delta t = 500 \times 0.0100 \div 0.100 = 50.0$ V.
3. The current in a 0.200 H inductor changes at 30.0 A s^{-1}. Find the size of the back EMF.
   $\varepsilon = L\Delta I \div \Delta t = 0.200 \times 30.0 = 6.00$ V.
4. A transformer has 920 primary turns on a 230 V supply. How many secondary turns give 10.0 V, and what is the primary current when the secondary supplies 2.30 A, if it is ideal?
   $N_s = N_p \times V_s \div V_p = 920 \times 10.0 \div 230 = 40$ turns; $I_p = V_sI_s \div V_p = 10.0 \times 2.30 \div 230 = 0.100$ A.
5. Calculate the final current and the time constant.
   $I = \varepsilon \div R = 10.0 \div 5.00 = 2.00$ A; $\tau = L \div R = 2.50 \div 5.00 = 0.500$ s (Achieved).
6. Calculate the rate at which the current starts to increase, and explain why the current does not jump straight to its final value.
   At the instant of closing $I = 0$, so there is no voltage across the resistance and the inductor has all 10.0 V: $\Delta I \div \Delta t = \varepsilon \div L = 10.0 \div 2.50 = 4.00$ A s^{-1}. The growing current makes a growing flux in the coil, which induces a back EMF opposing the increase (Lenz's law), so the current can only rise gradually (Merit).
7. Calculate the EMF across the inductor 0.300 s after the switch is closed.
   V_L = ε e^(−t ÷ τ) = 10.0 × e^(−0.300 ÷ 0.500) = 10.0 × 0.549 = 5.49 V (Excellence; 0.300 s is less than one τ, so more than 37% of 10.0 V is sensible).
8. Calculate the energy stored once the current is steady, and explain why a large voltage appears across the switch when it is opened.
   $E = \frac{1}{2}LI^2 = \frac{1}{2} \times 2.50 \times 2.00^2 = 5.00$ J. Opening the switch makes the current fall to zero in a very short time, so the flux through the coil collapses very quickly. The induced EMF, $L\Delta I \div \Delta t$, is very large and, by Lenz's law, acts to keep the current flowing; it appears across the opening switch contacts, and much of the 5.00 J stored in the magnetic field is released in the spark (Excellence links the rapid change, the size of the EMF and the stored energy).
9. Correct this statement: "A strong magnet sitting still inside a coil induces a large EMF."
   Only a changing flux induces an EMF; a stationary magnet in a stationary coil induces nothing.
10. Correct this statement: "When the switch closes, the current jumps to ε ÷ R and the inductor's voltage is zero."
    At the instant of closing the current is zero and the inductor has the full supply voltage; the current then rises with $\tau = L \div R$.
11. Correct this statement: "A step-up transformer gives you more power, because the voltage goes up."
    At best power out equals power in, so when the voltage steps up, the current steps down.
12. Correct this statement: "A transformer connected to a car battery will step 12 V up to 230 V."
    A steady DC current makes no changing flux, so a transformer gives no output from DC.

Answer key (for parents and tutors)

1. Find the peak voltage of a 12.0 V rms AC supply.
   $V_{max} = \sqrt{2} \times 12.0 = 17.0$ V.
2. Find the reactance of a 0.0500 H inductor at 1000 Hz.
   $X_L = 2\pi fL = 2\pi \times 1000 \times 0.0500 = 314\ \Omega$.
3. A 1.00 kΩ resistor and a 2.20 µF capacitor are in series with a 10.0 V rms, 100 Hz supply. Find X_C, the impedance and the current.
   $X_C = 1 \div (2\pi \times 100 \times 2.20 \times 10^{-6}) = 723\ \Omega$; $Z = \sqrt{(1000^2 + 723^2)} = 1234\ \Omega$, about 1.23 kΩ; $I = 10.0 \div 1234 = 8.10 \times 10^{-3}$ A (8.10 mA).
4. An AM tuner has a 250 µH coil and a 177 pF capacitor. Find its resonant frequency.
   $f_0 = 1 \div (2\pi\sqrt{(250 \times 10^{-6} \times 177 \times 10^{-12})}) = 7.57 \times 10^5$ Hz, about 757 kHz.
5. Calculate the resonant frequency of the circuit.
   $f_0 = 1 \div (2\pi\sqrt{(0.150 \times 22.0 \times 10^{-6})}) = 1 \div (2\pi \times 1.817 \times 10^{-3}) = 87.6$ Hz (Achieved).
6. Calculate the rms current at resonance.
   At resonance $X_L = X_C$, so $Z = R = 50.0\ \Omega$ and $I = 6.00 \div 50.0 = 0.120$ A (Merit with the reason).
7. Calculate the rms current when the frequency is 50.0 Hz.
   $X_L = 2\pi \times 50.0 \times 0.150 = 47.1\ \Omega$; $X_C = 1 \div (2\pi \times 50.0 \times 22.0 \times 10^{-6}) = 144.7\ \Omega$; $Z = \sqrt{(50.0^2 + (47.1 - 144.7)^2)} = 109.6\ \Omega$; $I = 6.00 \div 109.6 = 0.0547$ A (Excellence for the full calculation).
8. At 50.0 Hz, state whether the current leads or lags the supply voltage, calculate the phase angle, and explain why.
   Below resonance X_C is larger than X_L, so the capacitor's voltage outweighs the inductor's and the circuit behaves as a capacitor: the current leads the supply voltage. $\tan\varphi = (X_C - X_L) \div R = 97.6 \div 50.0$, so $\varphi = 62.9°$. On the phasor diagram the net reactive voltage points down, so the supply voltage lies below the current phasor (Excellence links the reactances to the phase).
9. Correct this statement: "The supply voltage is 7.28 + 9.54 = 16.8 V."
   V_R and V_L are 90° out of phase, so they add as phasors: $\sqrt{(7.28^2 + 9.54^2)} = 12.0$ V.
10. Correct this statement: "Mains is 230 V, so the voltage never goes above 230 V."
    230 V is the rms value; the peak is $230 \times \sqrt{2} = 325$ V.
11. Correct this statement: "In an inductor the current leads the voltage."
    In an inductor the voltage leads the current by 90°; in a capacitor the current leads.
12. Correct this statement: "$X_L = fL = 50.0 \times 0.500 = 25.0\ \Omega$."
    $X_L = \omega L = 2\pi fL$, so it is 157 Ω; leaving out 2π is a common slip.

Answer key (for parents and tutors)

1. The wind speed rises from 5 m s^{-1} to 10 m s^{-1}. By what factor does the power in the wind change?
   $P \propto v^3$ and $10 \div 5 = 2$, so the power is multiplied by $2^3 = 8$.

2. Find the power in the wind through a turbine with 40.0 m blades in a 12.0 m s^{-1} wind, using $\rho = 1.20$ kg m^{-3}.
   $A = \pi \times 40.0^2 = 5027$ m², $P = 0.5 \times 1.20 \times 5027 \times 12.0^3 = 5.21 \times 10^6$ W, which is 5.21 MW.

3. A line with resistance 5.00 Ω carries 400 A. Find the power lost as heat.
   $P = I^2R = 400^2 \times 5.00 = 8.00 \times 10^5$ W, which is 800 kW.

4. The same power is sent at twice the voltage. Find the new power lost.
   Twice the voltage halves the current to 200 A, so $P = 200^2 \times 5.00 = 2.00 \times 10^5$ W, which is 200 kW, a quarter of before.

5. Use the 2024 table to find hydro's share of New Zealand's electricity.
   $23\,490 \div 43\,879 = 0.535$, so 53.5%.

6. Correct this statement: "Wind is free, so doubling the number of turbines doubles our electricity whatever the weather."
   Output depends on wind speed cubed, so in calm weather extra turbines add almost nothing; storage or backup is still needed.

7. Correct this statement: "My position is that renewables are good, and my action is to tell people to use less power."
   State a specific position and actions, and use the physics ($P = \frac{1}{2}\rho Av^3$, I^2R losses) to justify why each would work.

8. Correct this statement: "This website says wind farms are unreliable, so they are."
   Check who wrote it, when, and whether measured data such as MBIE's statistics support the claim.

9. Correct this statement: "Transmission loss is $P = V^2/R$ with the line's full voltage, so higher voltage loses more."
   The loss depends on the current through the lines, $P = I^2R$; higher voltage means a smaller current and less loss.