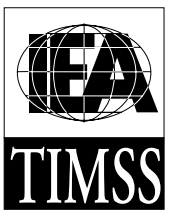
Released Physics Items
Population 3



PHYSICS NOTATION

Vectors are shown in bold italic type ***v***, ***F***, ***E***, ...

Variables and magnitudes of vectors are shown in italic type *t*, *v*, *F*, ...

SELECTED PHYSICAL CONSTANTS

acceleration due to gravity	g	$9.8\ ms^{-2}$
electron mass	m_e	9.11×10^{-31} kg
electron charge	e	1.60×10^{-19} C
proton mass	m_p	1.67×10^{-27} kg
speed of light	c	$3.0 \times 10^{8}\ ms^{-1}$
Boltzmann's constant	*k*	1.38×10^{-23} J/K
Planck's constant	*h*	6.63×10^{-34} Js
Avogadro's number	N_A	6.02×10^{23} molecules/mole
Gravitational constant	G	$6.67 \times 10^{-11}\ Nm^2kg^{-2}$
permeability constant	μ_0	$1.26 \times 10^{-6}\ Hm^{-1}$
permittivity constant	ε_0	$8.85 \times 10^{-12}\ Fm^{-1}$
universal gas constant	R	8.32 J/(mole)(K)
pressure: 1 atmosphere		$1.01 \times 10^{5}\ Nm^{-2}$

SELECTED PHYSICS FORMULAE

Mechanics

$$v = u + at$$

$$s = ut + \frac{1}{1}at^2$$

$$E_k = \frac{1}{2}mv^2$$

$$E_p = mgh$$

$$E_{spring} = \frac{1}{2}\mathrm{k}x^2$$

$$F = ma$$

$$Fdt = dp$$

$$F = \mathrm{G}\frac{m_1 m_2}{r^2}$$

$$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$$

$$p = p_0 + \rho gh$$

$$dW = \boldsymbol{F} \bullet d\boldsymbol{s}$$

Heat, Kinetic Theory

$$Q = cm\Delta t = C\Delta t$$

$$\Delta Q = \Delta U + \Delta W$$

$$pV = NkT = n\mathrm{R}T$$

$$\frac{1}{2}m\bar{v}^2 = \frac{3}{2}kT$$

$$\Delta W = p\Delta V$$

Light, Waves

$$v = f\lambda = \frac{\lambda}{T}$$

$$n_1 \sin\alpha_1 = n_2 \sin\alpha_2$$

$$d\sin\alpha_{\mathrm{n}} = \mathrm{n}\lambda$$

$$\frac{1}{a} + \frac{1}{b} = \frac{1}{f}$$

Electricity and Magnetism

$$V = RI$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$P = VI = RI^2$$

$$\varepsilon = rI + RI$$

$$E = \frac{F}{q}$$

$$E_p = qV$$

$$\varepsilon = -\frac{d\phi}{dt}$$

$$\varepsilon = lvB$$

$$F = IlB\sin\alpha = qvB\sin\alpha$$

$$B = \frac{\mu_0 I}{2\pi r}$$

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

Relativity, Quantum Physics and Astrophysics

$$L = L_0\sqrt{1-\frac{v^2}{\mathrm{c}^2}}$$

$$T = \frac{T_0}{\sqrt{1-\frac{v^2}{\mathrm{c}^2}}}$$

$$E = \frac{E_0}{\sqrt{1-\frac{v^2}{\mathrm{c}^2}}}$$

$$E_0 = m_0\mathrm{c}^2$$

$$E_\nu = h\nu$$

$$p_\nu = \frac{h\nu}{\mathrm{c}} = \frac{h}{\lambda}$$

$$h\nu = W + E_k$$

$$\lambda = \frac{h}{mv}$$

$$\Delta p\Delta x \geq \frac{h}{4\pi}$$

$$E = -\frac{B}{n^2}$$

G1. Electrons enter a uniform magnetic field at an angle of 90° to the field. A magnetic force ***F*** acts on the electrons causing them to follow a circular path with radius *R*.

If the electrons enter the field at a greater speed, what happens to the magnitude of the magnetic force *F* and the radius *R*?

A. *F* decreases and *R* increases.

B. *F* increases and *R* decreases.

C. *F* increases and *R* increases.

D. Neither *F* nor *R* change.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	C	Electricity and Magnetism	Theorizing, Analyzing, and Solving Problems	41%	644

G2. When a small volume of water is boiled, a large volume of steam is produced. Why?

A. The molecules are further apart in steam than in water.

B. Water molecules expand when heated.

C. The change from water to steam causes the number of molecules to increase.

D. Atmospheric pressure works more on water molecules than on steam molecules.

E. Water molecules repel each other when heated.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	A	Heat	Theorizing, Analyzing, and Solving Problems	65%	502

G3. A jar of oxygen gas and a jar of hydrogen gas are at the same temperature.

Which of the following has the same value for the molecules of both gases?

A. the average velocity

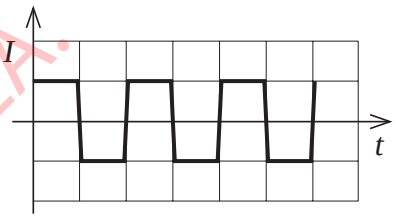
B. the average momentum

C. the average force

D. the average kinetic energy

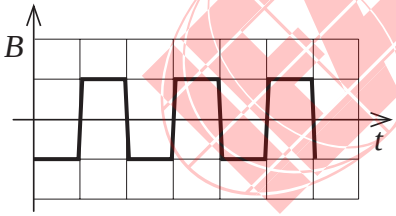
Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	D	Heat	Understanding	41%	637

G4. A coil is positioned in a varying magnetic field ***B*** which causes an induced current *I* in the coil as shown in the current-time (*I*-*t*) diagram below.

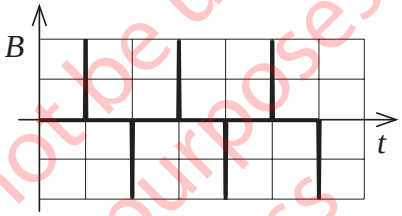


Which one of the following diagrams best represents the variation of the magnetic field?

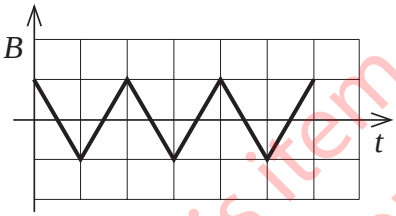
A.



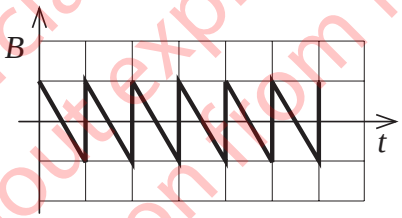
B.



C.

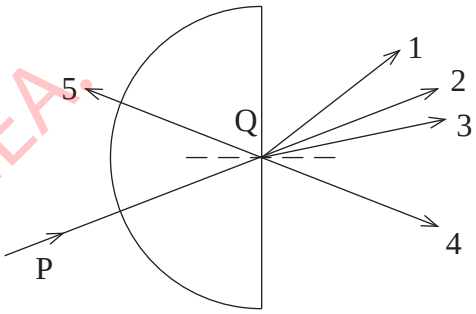


D.



Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	C	Electricity and Magnetism	Using Tools, Routine Procedures, and Science Processes	34%	682

G5. This item refers to the following diagram.



A ray of light passes from P to Q through a semicircular glass block in air.

Which arrow shows the direction in which the refracted ray of light would travel after leaving Q?

A. 1

B. 2

C. 3

D. 4

E. 5

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	A	Wave Phenomena	Theorizing, Analyzing, and Solving Problems	37%	664

G6. By what process do most stars release energy?

A. Electromagnetic induction resulting from strong magnetic fields

B. Rapid rotation of the star

C. Radioactivity in the interior of the star

D. Nuclear fusion in the interior of the star

E. Heat which was stored when the star was 'born'

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	D	Modern Physics: Particle, Quantum and Astrophysics, and Relativity	Understanding	59%	541

G7. A car manufacturer carries out a series of tests on a new model. Two cars, P and Q, of equal mass, moving at the same speed, are on a collision course as shown in Figure 1. A third car, R, of the same mass as the others and moving at the same speed, is on a collision course with an immovable wall of very high mass, as shown in Figure 2. In both cases the cars come to rest after collision.

Figure 1

Figure 2

The amount of kinetic energy transformed into energy of deformation and heat in the case of car P is

A. greater than that of car R.

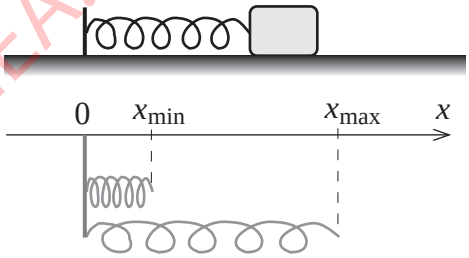
B. equal to that of car R.

C. less than that of car R.

D. not possible to answer because of insufficient information.

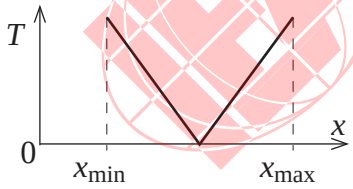
Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	B	Mechanics	Theorizing, Analyzing, and Solving Problems	30%	719

G8. A block oscillates with negligible friction on the end of a spring as shown in the figure below. The minimum and maximum lengths of the spring as it oscillates are, respectively, x_{min} and x_{max}.

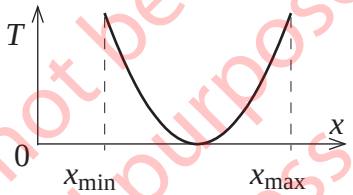


Which one of the following graphs represents the total mechanical energy (T) of the block and spring system as a function of x?

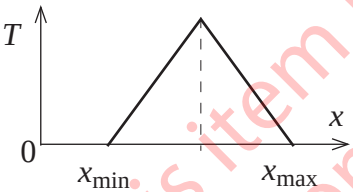
A.



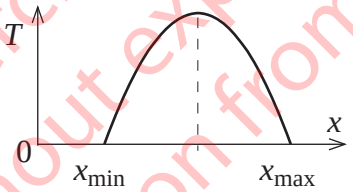
B.



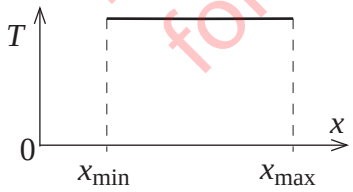
C.



D.

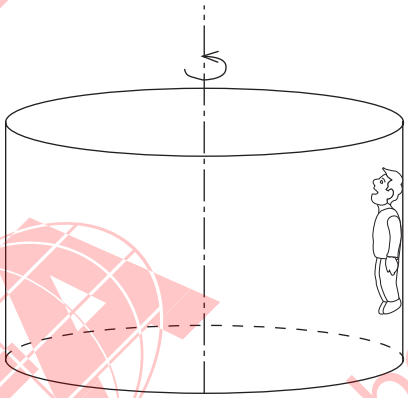


E



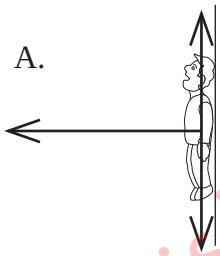
Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	E	Mechanics	Using Tools, Routine Procedures, and Science Processes	36%	676

G9. The figure below shows a special sort of amusement park ride. As the ride starts to rotate about its central vertical axis the floor drops slowly but the rider does not. The rider is pressed against the rough inside wall of the rotating cylinder and remains at rest with respect to the wall. The rider's feet are not in contact with the floor.

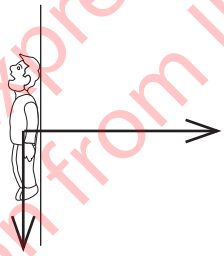


Which one of the following diagrams best represents the real forces acting on the rider?

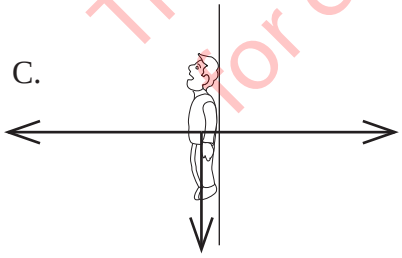
A.



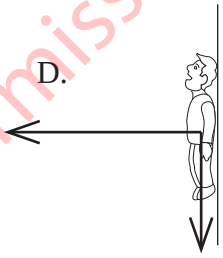
B.



C.



D.



Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	A	Mechanics	Theorizing, Analyzing, and Solving Problems	20%	802

G10. What is the minimum voltage across the electrodes of an X-ray tube which will produce X-rays with wavelength λ?

A. $\frac{hf}{\lambda}$

B. $\frac{hc}{e\lambda}$

C. $\frac{h\lambda}{ec}$

D. $\frac{h\lambda}{e}$

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	B	Modern Physics: Particle, Quantum and Astrophysics, and Relativity	Theorizing, Analyzing, and Solving Problems	32%	698

G11. The water level in a small aquarium reaches up to a mark A. After a large ice cube is dropped into the water, the cube floats and the water level rises to a new mark B.

What will happen to the water level as the ice melts? Explain your reasoning.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Heat	Theorizing, Analyzing, and Solving Problems	14%	762

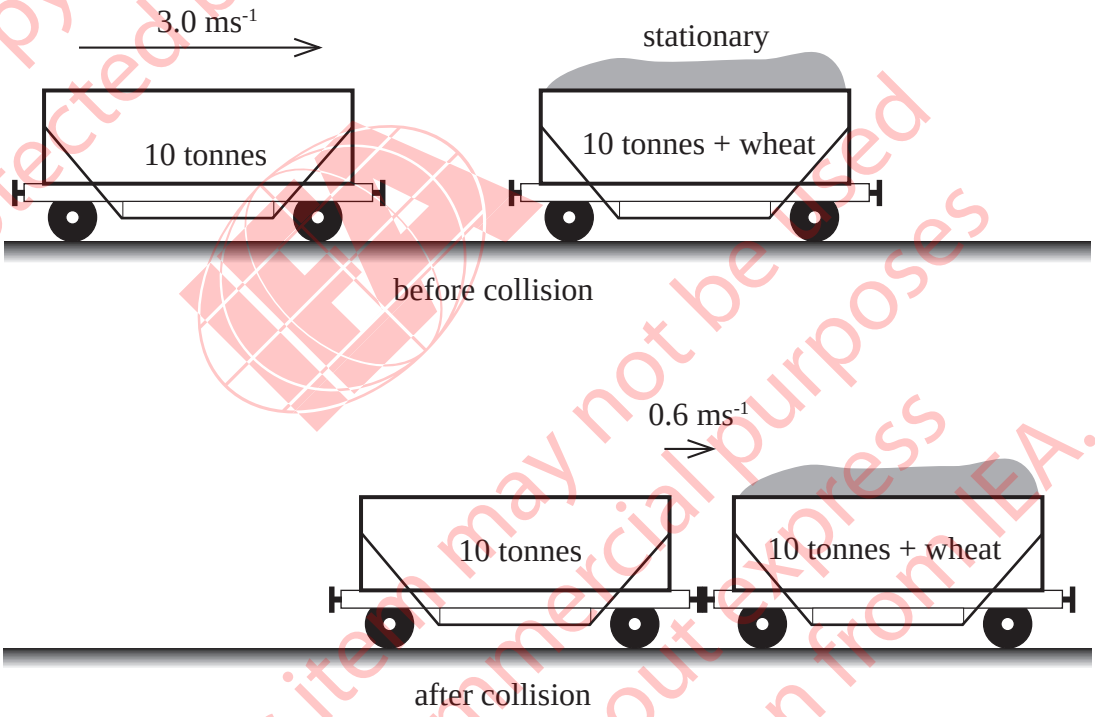
G11. The water level in a small aquarium reaches up to a mark A. After a large ice cube is dropped into the water, the cube floats and the water level rises to a new mark B.

What will happen to the water level as the ice melts? Explain your reasoning.

Code	Response
	Correct Response
20	Same level. Response refers to the fact that the volume (or mass) of the water displaced by the ice is equal to the volume (or mass) of the water produced when the ice is melted (Archimedes' principle). *Example: Level is the same because the ice displaces the same volume of water as when it melts.*
29	Other acceptable responses.
	Partial Response
10	Same level. Incomplete or incorrect explanation. *Examples: a) Ice and water has the same mass.* *b) Ice has less density than water.*
11	Same level. No explanation.
19	Other partially correct responses.
	Incorrect Response
70	Rising level, with or without explanation.
71	Sinking level. The water has smaller volume/greater density/"molecules are closer together" than the ice OR the ice has greater volume/smaller density/"molecules are further apart" than the water.
72	Sinking level. Because ice contains air.
73	Sinking level. As the ice melts the mass decreases (or disappears).
74	Sinking level. With other or without explanation.
79	Other unacceptable responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

G12. An empty railway truck of mass 10 tonne (1.0×10^4 kg) moving with a speed of 3 ms^{-1} collides with an identical stationary railway truck loaded with wheat. The two trucks couple together during the collision and then move together along the railway track with a speed of 0.6 ms^{-1}.

The situations before and after the collision are shown in the figure below.

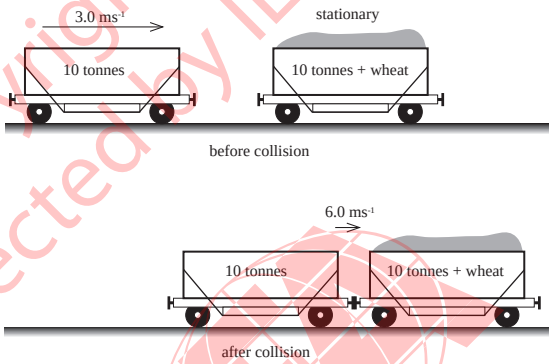


Use this information to calculate the mass of wheat carried in the loaded truck. Show your work.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Mechanics	Theorizing, Analyzing, and Solving Problems	36%	647

G12. An empty railway truck of mass 10 tonne (1.0×10^4 kg) moving with a speed of 3 ms^{-1} collides with an identical stationary railway truck loaded with wheat. The two trucks couple together during the collision and then move together along the railway track with a speed of 0.6 ms^{-1}.

The situations before and after the collision are shown in the figure below.



Use this information to calculate the mass of wheat carried in the loaded truck. Show your work.

Code	Response
	Correct Response
20	m = 30 tonnes, using the law of conservation of momentum. *Example:* $\sum mv$ *(before)* = $\sum mv$ *(after)* $m_1 v_1 = (m_1 + m_2 + x)\, v_2$ *(10t) (3.0m/s) = (20t + x) (0.6 m/s)* *x = 30t*
	Partial Response
10	As code 20, but missing or wrong units.
11	m = 30 tonnes. No work shown.
12	m = 40 tonnes; the mass of the truck is not taken into account, but conservation of momentum is correctly stated.
13	Conservation of momentum is correctly stated; calculation error.
14	Conservation of momentum is correctly stated, but no value for mass calculated.
19	Other partially correct responses.
	Incorrect Response
70	Incorrect approach, using the principle of conservation of energy.
79	Other unacceptable responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

G13. A car moving at constant speed with a siren sounding comes towards you and then passes by.

Describe how the frequency of the sound you hear changes.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Wave Phenomena	Theorizing, Analyzing, and Solving Problems	36%	673

G-13 Coding Guide

G13. A car moving at constant speed with a siren sounding comes towards you and then passes by.

Describe how the frequency of the sound you hear changes.

Code	Response
	Correct Response
10	Response refers to the fact that the frequency (or the pitch) is higher as the car approaches and is lower as the car moves away (compared to the frequency when the car is at rest). *Examples: a) Because of Doppler effect the frequency changes from higher to lower.* *b) The pitch is higher as the car comes closer and lower after it goes by.*
11	Refers to the fact that the change in frequency is described as change in wavelength, from becoming shorter (as car approaches) to becoming longer (as car moves away). *Example: When the car approaches, the wavelength of the sound is shorter than it is when the car moves away.*
19	Other acceptable responses.
	Incorrect Response
70	Refers to the fact that the frequency (or the pitch) is changing from lower to higher than normal.
71	Refers to the fact that the wavelength is changing from longer to shorter.
72	Only the loudness of the sound is described. *Example: At a distance the sound is faint but it gets louder until it is by you and then the sound fades away.*
73	Refers to the fact that the frequency (or the pitch or the wavelength) is continually changing as the car moves. *Example: The nearer the car comes, the higher is the frequency.*
79	Other incorrect responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

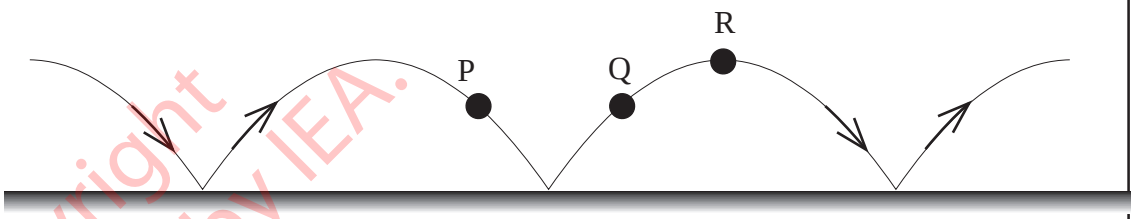
G14. Draw a diagram to show the paths of alpha particles, electrons, and gamma rays as they pass between two parallel metal high-voltage plates in a vacuum.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Modern Physics: Particle, Quantum and Astrophysics, and Relativity	Understanding	27%	746

G14. Draw a diagram to show the paths of alpha particles, electrons, and gamma rays as they pass between two parallel metal high-voltage plates in a vacuum.

Code	Response
	Correct Response
10	Alpha particles are deflected towards the negative plate, the electrons towards the positive plate, and the gamma rays are not deflected.
11	Alpha particles and electrons are deflected in opposite directions, gamma rays are not deflected. Charges on the plates are **not** indicated, or the plates are missing.
	Incorrect Response
70	Alpha particles and electrons are interchanged. Gamma correct.
71	Gamma rays are deflected or missing; the rest correct.
72	Electrons are deflected incorrectly or missing; the rest correct.
73	Alpha particles are deflected incorrectly or missing; the rest correct.
79	Other incorrect responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

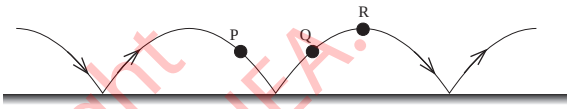
G15. The figure shows the trajectory of a ball bouncing on a floor, with negligible air resistance.



Draw arrows on the figure showing the direction of the acceleration of the ball at points P, Q and R.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Mechanics	Understanding	16%	840

G15. The figure shows the trajectory of a ball bouncing on a floor, with negligible air resistance.



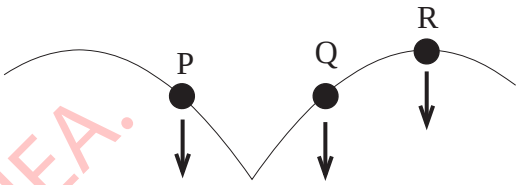
Draw arrows on the figure showing the direction of the acceleration of the ball at points P, Q and R.

Note: No explanation is required.

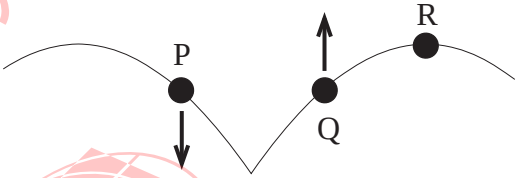
Code	Response
	Correct Response
10	The acceleration is parallel to g, downwards arrows at P, Q and R. (See following diagrams).
	Incorrect Response
70	The acceleration is parallel to g, downwards arrow at P, upwards at Q and zero at R.
71	The acceleration is parallel to g, downwards arrow at P, upwards at Q, either upwards or downwards at R.
72	The acceleration has the same direction as the motion (at least at P and Q). Any response at R.
73	The acceleration has the same direction as the motion at P, the opposite direction from the motion at Q. Any response at R.
74	The acceleration has the direction perpendicular to the motion (at least at P and Q).
79	Other incorrect responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

Continued Next Page

Code 10



Code 70



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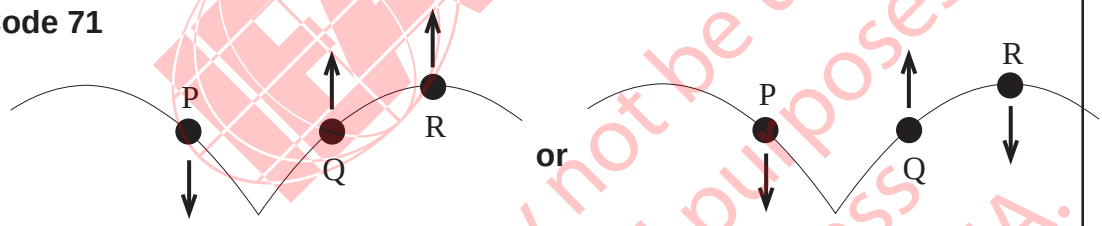
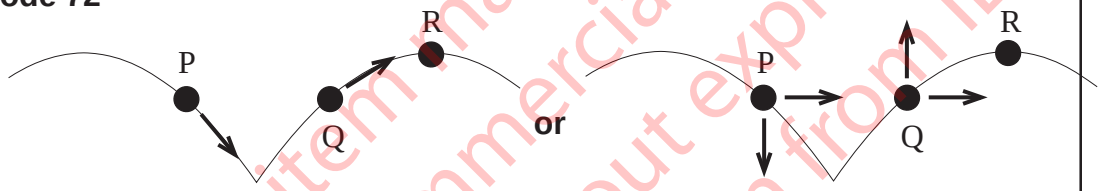
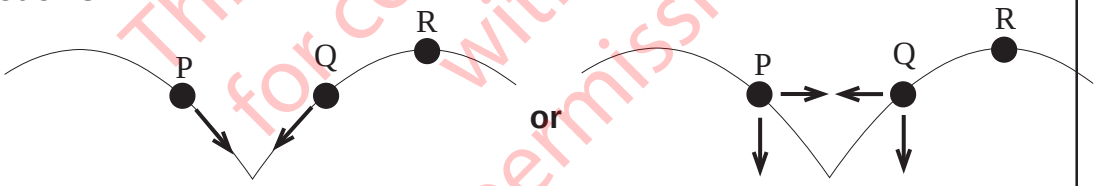


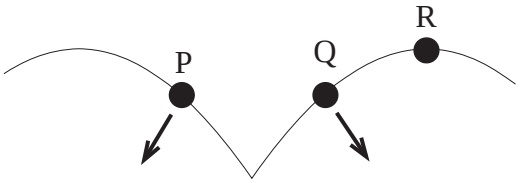
Code 72



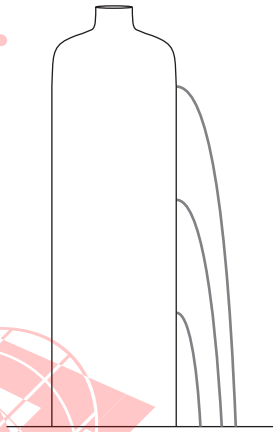
Code 73



Code 74



G16. The figure shows a common plastic bottle (1 L) filled with water and with three holes in it, so that the water runs out of the holes.



Explain what is wrong with the figure.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Mechanics	Theorizing, Analyzing, and Solving Problems	9%	899

G16. The figure shows a common plastic bottle (1 L) filled with water and with three holes in it, so that the water runs out of the holes.

Explain what is wrong with the figure.

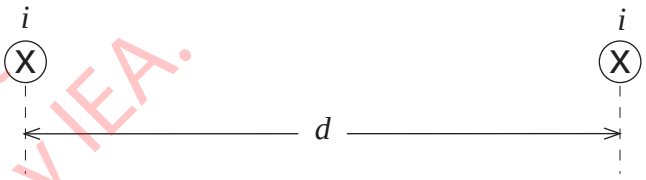
Note: A fully correct response should refer to the following:
i) The relative horizontal distances of the water from the three holes are shown incorrectly in the figure because
ii) The pressure (horizontal speed) of the water should increase with increasing depth.
A full description of the comparative horizontal distances from the three holes is not required for full credit, but if it is included, is should indicate that the water from the middle hole will actually reach the longest distance horizontally.

Code	Response
	Correct Response
20	Response refers to the fact that the pressure and/or horizontal speed of the water should increase with depth and that the horizontal distances are not correctly indicated. *Example: The pressure will increase with depth due to water above, so the water jets will have other paths.*
29	Other correct responses.
	Partial Response
10	Responses similar to Code 20, but explicitly stating that the water from the lowest hole will reach the longest distance horizontally. (Not correct. It can be shown that the water from the middle hole will reach the longest distance.) *Example: There's added pressure from water above so the water from the bottom hole will travel farther. The distance gets smaller the higher the holes are made.*
11	As code 20 but no reference to the aspect of incorrect horizontal distances. *Example: The water from the bottom holes should have greater speed than the top hole since the pressure is greater.*
19	Other partially correct responses.

Continued Next Page

	Incorrect Response
70	Refers to the fact that the water from all the three holes should reach the same distance horizontally. *Example: Gravity pulls each stream down by the same amount, so they should hit the ground in the same place.*
71	States that there is no horizontal displacement of water. *Example: The water from all 3 holes just runs down the side of the container and hits the ground in the same place.*
79	Other incorrect responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

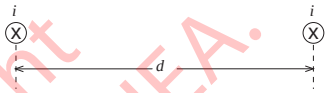
G17. The diagram shows two long parallel wires a distance d apart. Each carries a current *i* directed into the page.



Draw an arrow on the right-hand wire to show the direction of the force on it due to the current in the left-hand wire.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Electricity and Magnetism	Theorizing, Analyzing, and Solving Problems	30%	715

G17. The diagram shows two long parallel wires a distance d apart. Each carries a current *i* directed into the page.



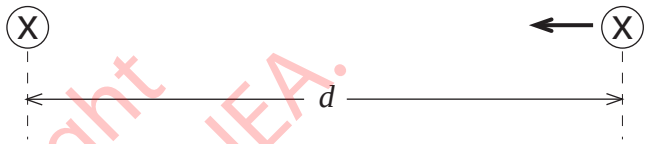
Draw an arrow on the right-hand wire to show the direction of the force on it due to the current in the left-hand wire.

Note: Apply the same codes if the arrow is drawn on the left-hand wire.

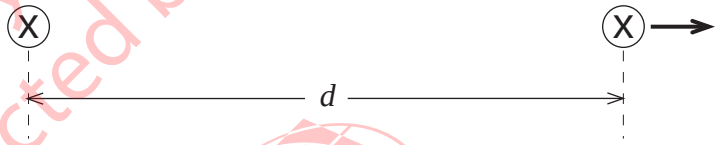
Code	Response
	Correct Response
10	Arrow showing attraction. (See following diagram).
	Incorrect Response
70	Arrow showing repulsion.
71	Arrow pointing upwards.
72	Arrow pointing downwards.
79	Other incorrect responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

Continued Next Page

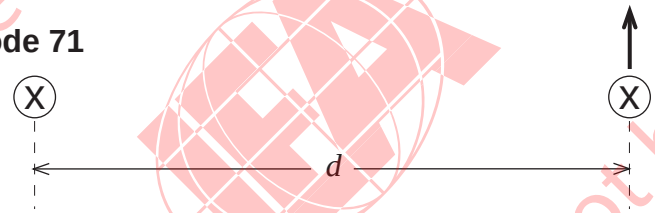
Code 10



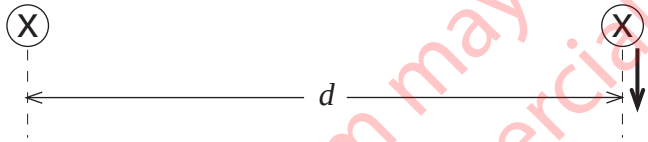
Code 70



Code 71



Code 72



G18. A stream of alpha particles is directed at a very thin sheet of gold.

Explain why most of the alpha particles pass through the sheet.

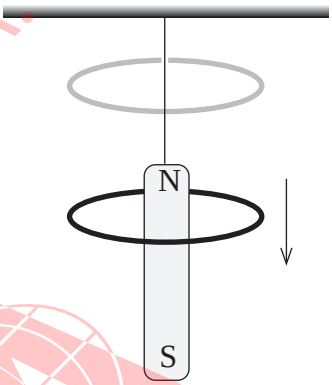
Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Modern Physics: Particle, Quantum and Astrophysics, and Relativity	Theorizing, Analyzing, and Solving Problems	10%	805

G18. A stream of alpha particles is directed at a very thin sheet of gold.

Explain why most of the alpha particles pass through the sheet.

Code	Response
	Correct Response
20	Explains that the diameter of a gold atom (or the distance between the nuclei) is very large compared to the diameter of a nucleus and an alpha particle. (Collisions with electrons will not have significant effects.) *Example: Within an atom there is almost only empty space because the nucleus is small, and an atom is very large compared to an alpha particle.*
29	Other correct.
	Partial Response
10	References general idea of empty space within the gold atom, but omits or incompletely describes relative sizes. *Example: An atom has a nucleus surrounded mostly by space so the alpha particles can pass through.*
19	Other partially correct.
	Incorrect Response
70	Refers to the fact that alpha particles have high (kinetic) energy (or high speed).
71	Refers to the fact that there is empty space **between** the atoms. *Example: The alpha particles just go around the gold atoms.*
72	Combination of code 70 and 71.
73	Refers to the wave nature (wavelength) of alpha particles.
74	Refers to the crystal structure of gold.
79	Other incorrect.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

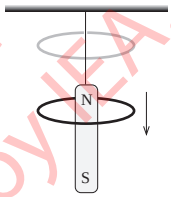
G19. A strong bar magnet hangs from a string with its north pole upwards. A light ring of aluminium is held above the magnet and allowed to fall down to the ground, as shown in the figure.



Explain why the ring takes longer to fall to the ground with the magnet present than it would without the magnet.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Electricity and Magnetism	Theorizing, Analyzing, and Solving Problems	14%	759

G19. A strong bar magnet hangs from a string with its north pole upwards. A light ring of aluminium is held above the magnet and allowed to fall down to the ground, as shown in the figure.



Explain why the ring takes longer to fall to the ground with the magnet present than it would without the magnet.

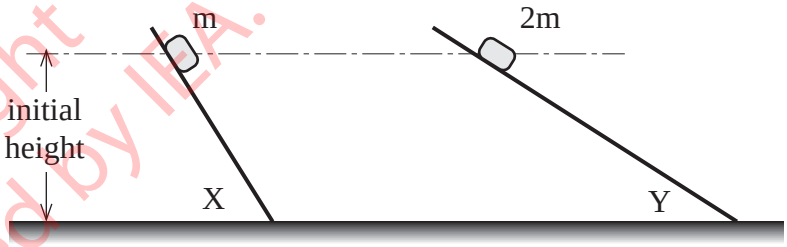
Note: A response may include the following aspects:
a) Changing flux while the ring is falling
b) Induction, i.e. induced current (or e.m.f.)
c) A force acting on the ring in the opposite direction of the motion
d) Reduced acceleration and therefore longer time to fall
For a complete response b and c are regarded as crucial

Code	Response
	Correct Response
20	Response refers to b and c, and in addition a and/or d. *Examples: a) There's an induced current in the ring. According to Lenz's law, this creates a force acting opposite the movement (upwards) which decreases the acceleration of the ring.* *b) The flux will change which creates induced current and an upwards force acting on the ring.*
21	Refers to b and c only. *Example: Because of an induced e.m.f., there will be a magnetic force acting on the ring upwards.*
29	Other acceptable responses such as reasons including conservation of energy.
	Partial Response
10	Refers to induction (b) or Lenz' law, with incorrect (incomplete) or without further reasoning. *Example: In Lenz's law it states that the inducing current has a force acting on the induced current which will create an opposition force to the induced field.*
19	Other partially correct responses.

Continued Next Page

Incorrect Response	
70	Responses expressing the idea that the magnet pushes (or pulls) on the ring due to the magnetic force from the magnet. Nothing recorded about induction. *Examples: a) Because the magnetic field is a force acting on the ring, the ring will fall slower.* *b) As the ring leaves the presence of the magnet, the attractive force works against gravity.* *c) The magnet makes resistance.*
79	Other unacceptable responses.
Nonresponse	
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

H1. Two boxes of mass m and 2m are allowed to slide down inclined planes X and Y, starting from rest at the same height. The two planes are of different slope and offer negligible friction to the motion of the boxes.



Which one of the following statements is NOT correct?

A. At the top of the planes one of the boxes had half the potential energy of the other box.

B. The boxes have the same speed at the bottom of the inclined planes.

C. The boxes take the same time to reach the bottom of the inclined planes.

D. The box on plane X has greater acceleration than the box on plane Y.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	C	Mechanics	Theorizing, Analyzing, and Solving Problems	39%	650

H2. Which one of the following statements about liquid evaporation is correct?

When a liquid evaporates

A. the temperature in the air above the liquid decreases.

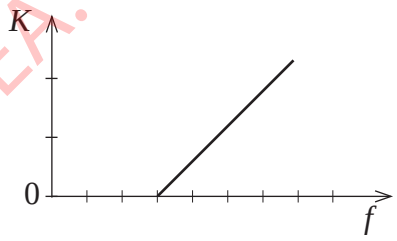
B. fast-moving liquid molecules near the surface escape to the air and the liquid gets warmer.

C. the gas pressure of the substance directly above the liquid depends only on the atmospheric pressure.

D. fast-moving liquid molecules near the surface escape to the air and the liquid gets colder.

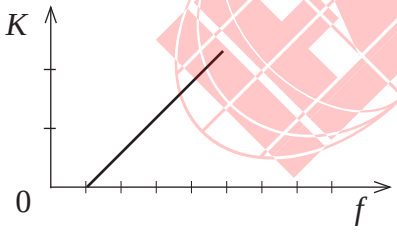
Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	D	Heat	Understanding	54%	570

H3. The graph shows the maximum kinetic energy (K) of electrons emitted from a certain metal by the photoelectric effect as a function of the frequency (f) of the incoming radiation.

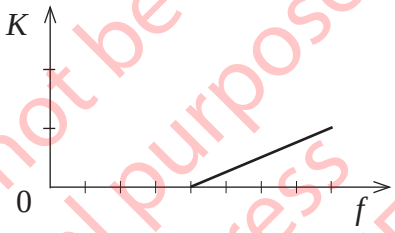


Which one of the following graphs best represents the kinetic energy-frequency relationship for another metal with a smaller work function? All the graphs have the same frequency scale and kinetic energy scale.

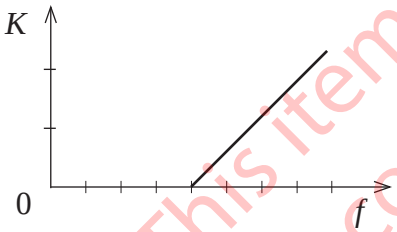
A.



B.



C.

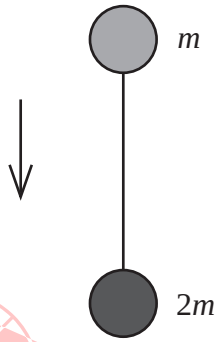


D.

H-3

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	A	Modern Physics: Particle, Quantum and Astrophysics, and Relativity	Using Tools, Routine Procedures, and Science Processes	39%	666

H4. Two spheres with masses m and $2m$ respectively are connected by a light string and suspended at rest. The system is released and falls freely, as shown in the figure.



If g is the acceleration due to gravity, what is the tension in the string as the system falls?

A. 0

B. mg

C. 2mg

D. 3mg

H-4

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	A	Mechanics	Theorizing, Analyzing, and Solving Problems	34%	696

H5. A spaceship passes an observer at a speed of 0.9 c. The observer knows that the length of the spaceship, measured at rest before it took off, was 100 m.

What is the length of the spaceship in flight as seen by the observer?

A. 19 m

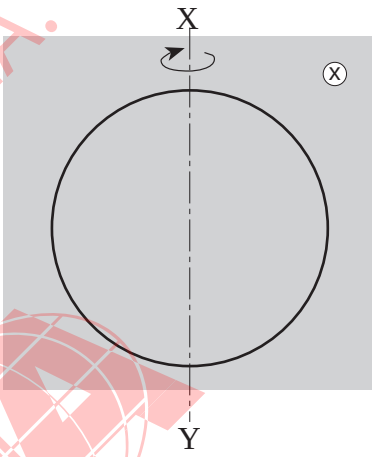
B. 44 m

C. 229 m

D. 526 m

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	B	Modern Physics: Particle, Quantum and Astrophysics, and Relativity	Theorizing, Analyzing, and Solving Problems	45%	619

H6. A circular wire coil rotates at a constant speed about the axis XY in a constant and uniform magnetic field ***B*** directed into the page. The figure shows the coil at an instant in which it lies in the plane of the page.



Magnetic field *B* into the page

After which of the following fractions of a rotation will the induced emf be a maximum?

A. 0

B. $\frac{1}{8}$

C. $\frac{1}{4}$

D. $\frac{1}{2}$

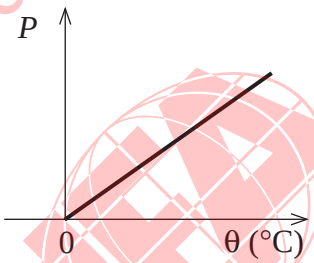
H-6

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	C	Electricity and Magnetism	Understanding	30%	716

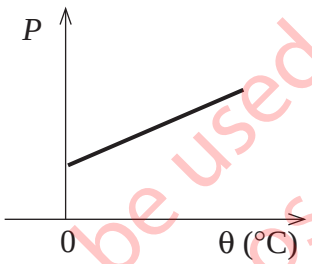
H7. A fixed mass of gas is heated at constant volume.

Which one of the following diagrams best shows the correct shape of the graph of pressure (P) against temperature (θ) for the gas? Temperature is measured in degrees Celsius (°C).

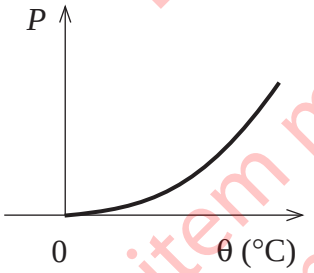
A.



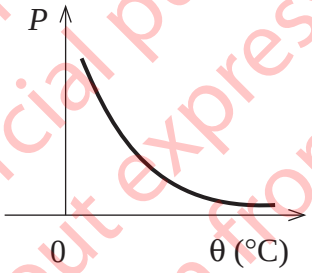
B.



C.

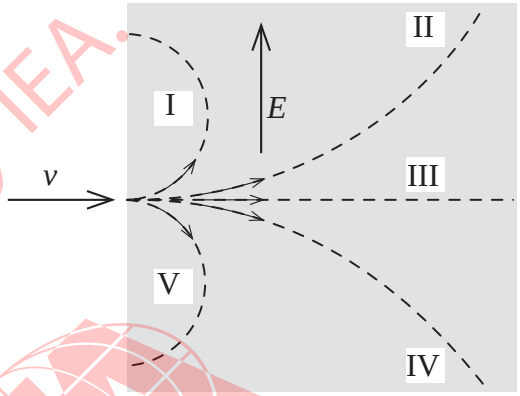


D.



Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	B	Heat	Using Tools, Routine Procedures, and Science Processes	41%	650

H8. Electrons enter a uniform electric field ***E*** with a velocity ***v*** as shown in the figure. The velocity ***v*** is perpendicular to the electric field ***E***.



Which one of the dashed paths (I, II, III, IV or V) best represents the path of the electrons in the electric field?

A. I

B. II

C. III

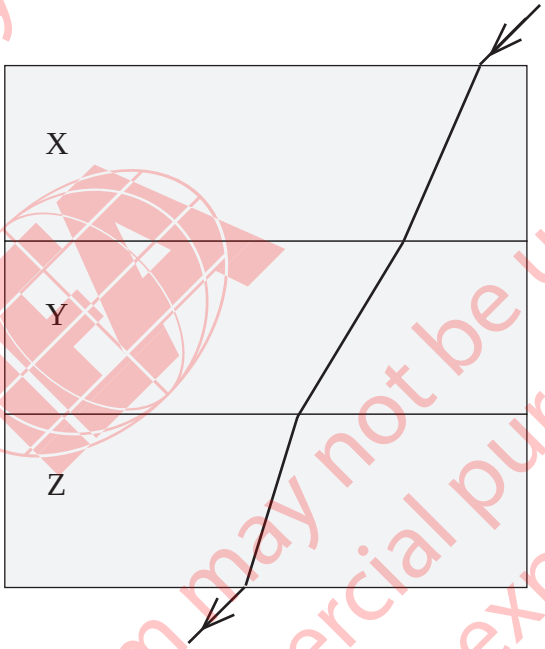
D. IV

E. V

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	D	Electricity and Magnetism	Understanding	32%	711

H9. A ray of blue light passes through a stack of three parallel-sided blocks made of different materials. The path of the beam is shown.

In which of the three blocks is the velocity of blue light greatest?



A. X

B. Y

C. Z

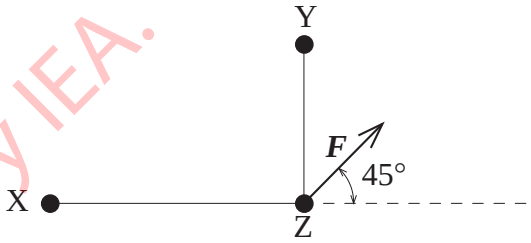
D. The velocity is the same in all the blocks.

E. The information given is insufficient to be able to say.

H-9

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	B	Wave Phenomena	Understanding	26%	747

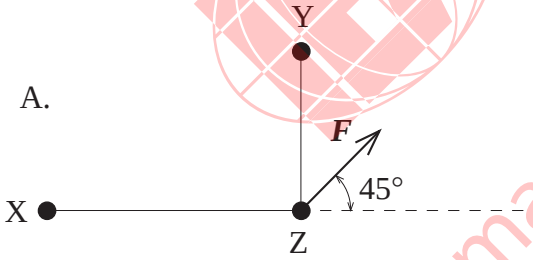
H10. The figure below shows three small charged spheres X, Y and Z. The distance between X and Z is greater than the distance between Y and Z. The vector sum of the electric forces on Z is denoted by ***F*.**



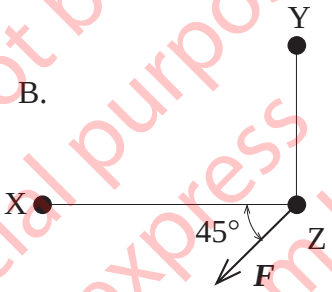
The two charged spheres X and Y are now interchanged.

Which one of the diagrams below best represents the vector sum of the electric forces on Z now?

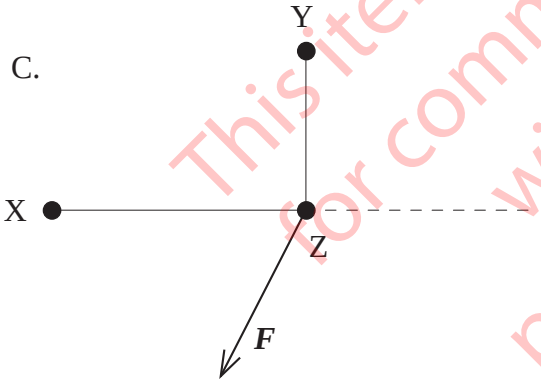
A.



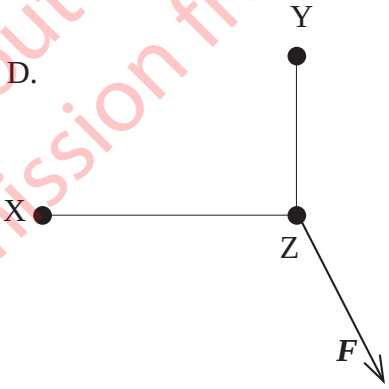
B.



C.

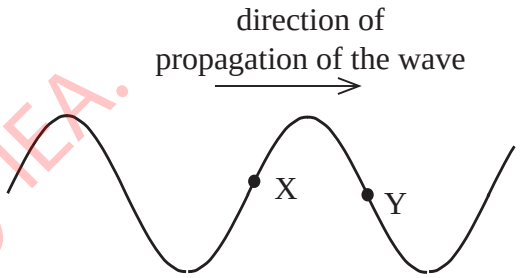


D.



Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	C	Electricity and Magnetism	Theorizing, Analyzing, and Solving Problems	32%	709

H12. The figure shows a wave moving to the right on a string.

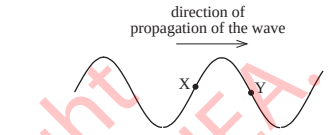


Draw an arrow at point X and one at point Y to show the direction of motion of the two points at the instant shown in the figure.

H-12

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Wave Phenomena	Theorizing, Analyzing, and Solving Problems	26%	752

H12. The figure shows a wave moving to the right on a string.

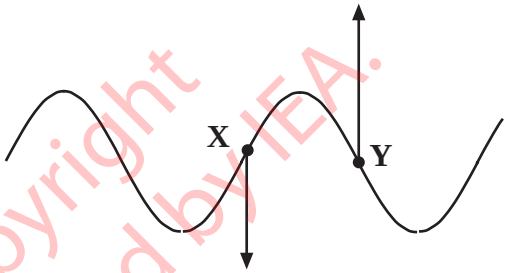


Draw an arrow at point X and one at point Y to show the direction of motion of the two points at the instant shown in the figure.

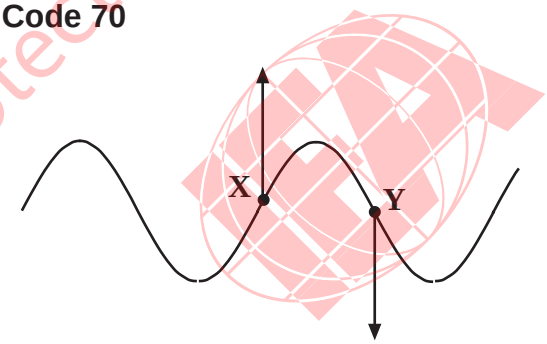
Code	Response
	Correct Response
10	Arrow downwards at X, upwards at Y. (See following diagram)
	Incorrect Response
70	Arrow upwards at X, downwards at Y.
71	Arrows to the right at both X and Y.
72	Arrows in direction of string motion at X and Y.
79	Other incorrect response.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

Continued Next Page

Code 10



Code 70



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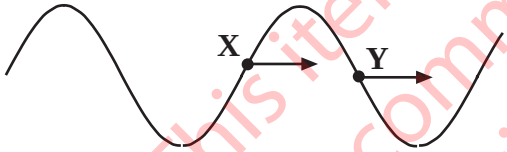

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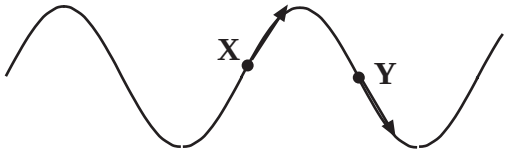
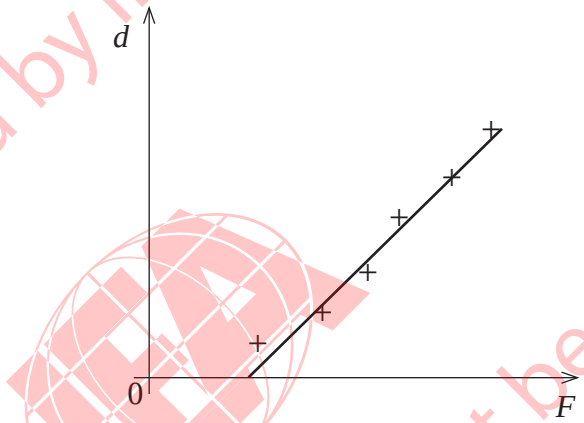


H13. A block is accelerated from rest along a horizontal table top by a constant unbalanced force ***F***. The experiment is repeated several times using a different value for the constant unbalanced force each time. For each force the distance *d* travelled by the block in the first 2.0 seconds is measured. The graph below shows the results of such an experiment.

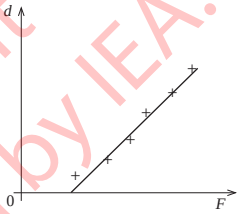


Explain why the graph line does not pass through the origin.

H-13

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Mechanics	Using Tools, Routine Procedures, and Science Processes	35%	690

H13. A block is accelerated from rest along a horizontal table top by a constant unbalanced force ***F***. The experiment is repeated several times using a different value for the constant unbalanced force each time. For each force the distance *d* travelled by the block in the first 2.0 seconds is measured. The graph below shows the results of such an experiment.

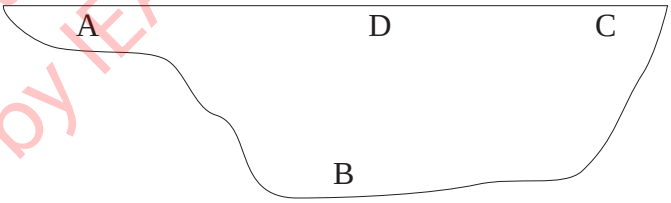


Explain why the graph line does not pass through the origin.

Note: Distinguish between students who mention friction, and those who do not.

Code	Response
	Correct Response
10	Refers to friction. Develops a formula for a graph outside origin. *Example: Newton's 2nd law gives: F – R = ma. And d = 1/2at^2. t is a constant, and this shows that d is proportional to F – R giving a straight line outside the origin.*
11	Refers to (static) friction. *Example: Because of friction there is a minimum value of the force before the block will move. Therefore the graph line will not pass through the origin.*
19	Other correct responses.
	Incorrect Response
70	Refers only to the fact that static friction is greater than kinetic friction.
71	Misinterpretation of the graph (e.g. one of the axes is time).
72	Refers to the fact that the force is not zero or cannot be zero.
79	Other incorrect responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

H14. Here is a cross-section of a lake in the mountains. The air temperature gets below freezing in the winter and stays below freezing for 3 months.

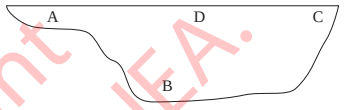


Not all of the water in the lake freezes. Which part of the lake will remain the warmest? Explain.

H-14

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Heat	Understanding	13%	804

H14. Here is a cross-section of a lake in the mountains. The air temperature gets below freezing in the winter and stays below freezing for 3 months.

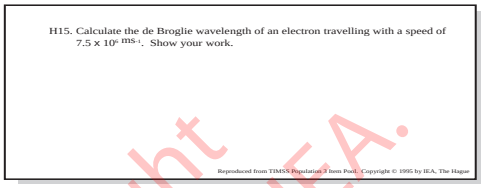


Not all of the water in the lake freezes. Which part of the lake will remain the warmest? Explain.

Code	Response
	Correct Response
20	B. Response refers to the maximum density of water (or the water is heaviest) at 4 degrees Celsius. *Example: Warmest at B because water has greatest density at 4˚ C so this water will stay there.*
29	Other acceptable responses.
	Partial Response
10	B. Refers to the fact that the water is 4 degrees Celsius at B without mentioning density.
11	B. Refers to the fact that ice will insulate this part of the water and/or that water is a bad heat conductor. *Examples: a) The surface will freeze first and then downwards.* *b) It takes time for heat and cold to get there.*
19	Other partially correct responses.
	Incorrect Response
70	B. No explanation.
71	B. Incorrect explanation referring to the heat from the earth (closer to the earth's center). *Example: The heat from the Earth will give heat to the water.*
72	B. Refers to the fact that hot water is heavier than cold water.
73	A/D/C with or without explanation.
76	Merely repeats information in the stem. *Example: B is the deepest point of the lake.*
79	Other unacceptable responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

H15. Calculate the de Broglie wavelength of an electron travelling with a speed of 7.5×10^6 ms^{-1}. Show your work.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Modern Physics: Particle, Quantum and Astrophysics, and Relativity	Theorizing, Analyzing, and Solving Problems	25%	759


H15. Calculate the de Broglie wavelength of an electron travelling with a speed of 7.5×10^6 ms^{-1}. Show your work.

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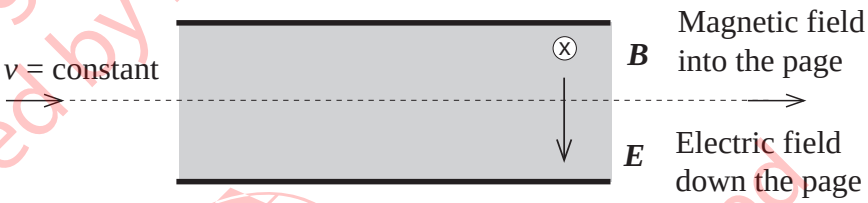
Note: Accept reasonable rounding and missing or wrong units.

Code	Response
	Correct Response
10	9.7 x 10^{-11} m: $\lambda = h/p = h/mv$.
11	9.7 x 10^{-11} m. No work shown.
12	9.7 x 10^{-11} m. Relativistic impulse (unnecessary) giving correct answer: $\lambda = \frac{h}{\frac{mv}{\sqrt{1-\frac{v^2}{c^2}}}}$
19	Other correct responses.
	Incorrect Response
70	Correct formula, but calculation missing or incorrect, such as exponential error.
71	$\lambda = v/f$, no conclusion.
79	Other incorrect responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

H16. An electron with charge e enters an area with a uniform magnetic field $\boldsymbol{B}$ and a uniform electric field $\boldsymbol{E}$. It continues its motion without any change in speed or direction of motion as the diagram shows. The magnetic field, directed into the page, is at right angles to the electric field, which is directed down the page.



Find an expression of the speed v of the electron in terms of E and B. Show your work.

H-16

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Electricity and Magnetism	Theorizing, Analyzing, and Solving Problems	21%	718

H16. An electron with charge *e* enters an area with a uniform magnetic field ***B*** and a uniform electric field ***E***. It continues its motion without any change in speed or direction of motion as the diagram shows. The magnetic field, directed into the page, is at right angles to the electric field, which is directed down the page.

Find an expression of the speed *v* of the electron in terms of *E* and *B*. Show your work.

Note: Vectors are shown in bold italic type

Code	Response
	Correct Response
20	***v*** = ***E***/***B*** (accept ***v*** = ***E***/***B***sin α) Balanced magnetic and electronic forces: q***vB*** = q***E***
21	***v*** = ***E***/***B*** (accept ***v*** = ***E***/***B***sin α.) Correct use of vector notation. *Example: q**v** x**B** + q**E** = 0* *then q**vB** (sin α) = q**E*** *α = 90° so **v** = **E**/**B**.*
	Partial Response
10	Correct reasoning. Incorrect use of vector notation. *Example: q**vB** = q**E** and then **v** = **E**/**B***
11	***v*** = ***E***/***B*** (accept ***v*** = ***E***/***B***sin α.) No work shown.
12	Correct formulas, but calculation error such as ***v*** = ***B***/***E***
13	Correct reasoning but one incorrect formula. (**Note**: Except II***B*** = q***vB*** is Code 79). *Example: F_1 = q**vB** and F_2 = qU, then **v** = U/**B***
19	Other partially correct responses. *Example: F_B = q**vB** and F_E = q**E***
	Incorrect Response
70	Incorrect responses referring to circular motion.
79	Other incorrect responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

H17. A 15 watt light bulb requires a current of 1.7 ampere for normal operation. Suppose a 12 volt car battery is to be used. In order to have the bulb glow normally, a resistor is connected in series with the light bulb.

What resistance should this resistor have? (The internal resistance of the battery can be ignored.) Show your work.

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Electricity and Magnetism	Theorizing, Analyzing, and Solving Problems	17%	745

H17. A 15 watt light bulb requires a current of 1.7 ampere for normal operation. Suppose a 12 volt car battery is to be used. In order to have the bulb glow normally, a resistor is connected in series with the light bulb.

What resistance should this resistor have? (The internal resistance of the battery can be ignored.) Show your work.

Code	Response
	Correct Response
20	r = 1.9 Ω. Starts by calculating the total resistance (7.1 Ω) and/or the resistance of the bulb (5.2 Ω). *Examples: a)* $R_{bulb} = P/I^2 = 15W/(1.7A)^2 = 5.2\Omega$ $R = R_{tot} - R_{bulb} = \frac{12V}{1.7A} - 5.2 = 1.9\Omega$ *b)* $R_T = \frac{V}{I} = \frac{12V}{1.7A} = 7.1\Omega$ $7.1\Omega = R + (15W/(1.7A)^2)$ $R = 7.1\Omega - 5.2\Omega = 1.9\Omega$
21	r = 1.9 Ω. Starts with the calculation of the voltage across the bulb (8.8 V). *Example:* $V_{bulb} = P/I = 15W/1.7A = 8.8V$ $12V - 8.8V = 3.17V$ $R = \frac{V}{I} = \frac{3.17V}{1.7A} = 1.87\Omega$
29	r = 1.9 Ω. Other approaches.
	Partial Response
10	r = 1.9 Ω. No work shown.
11	As code 20. Correct reasoning, but calculation error.
12	As code 21. Correct reasoning, but calculation error.
19	Other partially correct responses. (**Note:** This code should only be used if the student has arrived at some numeric solution of the the problem given).
	Incorrect Response
70	r = 12 V / 1.7 A = 7.1 Ω. Calculates total resistance.
71	Calculates the resistance of the bulb (about 5.2 Ω).
72	r = I / U = 1.7 / 12 V = 0.14 Ω. Inverts R = V/I relationship.
79	Other incorrect responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret
99	BLANK

H18. Jenny promises to bring a particle accelerator to class. She wheels in a television. The students laugh.

Explain (in up to 4 sentences) how Jenny can defend her statement that a television is a particle accelerator.

H-18

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Modern Physics: Particle, Quantum and Astrophysics, and Relativity	Theorizing, Analyzing, and Solving Problems	15%	783

H-18 Coding Guide

H18. Jenny promises to bring a particle accelerator to class. She wheels in a television. The students laugh.

Explain (in up to 4 sentences) how Jenny can defend her statement that a television is a particle accelerator.

Code	Response
	Correct Response
20	Response refers to electron emission and acceleration by an electric field (in a cathode-ray tube/electron gun). *Examples: a) The electrons emit from the cathode and are accelerated by a high anode voltage.* *b) In a TV electrons are accelerated by an electric field.*
29	Other acceptable explanations.
	Partial Response
10	Refers to accelerated electrons. No further, or incorrect explanation. *Examples: Electrons are accelerated in a TV.* *In a TV there is an electron gun accelerating electrons.*
19	Other partially correct responses.
	Incorrect Response
70	Light (particles), photons or radioactive radiation (particles) are sent towards the screen.
76	Merely repeats information from the stem *Example: A TV accelerates particles.*
79	Other incorrect responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

H19.

(a) Briefly outline an experiment Susan could do at her school, using echos on the playground wall to measure the speed of sound. Indicate what materials Susan would need, what measurements she will take, and what computations she will make.

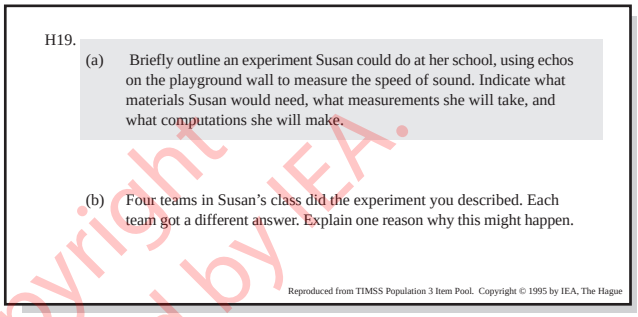
(b) Four teams in Susan's class did the experiment you described. Each team got a different answer. Explain one reason why this might happen.

H-19a

Part a

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Wave Phenomena	Investigating the Natural World	19%	747

H-19a Coding Guide



H19.

(a) Briefly outline an experiment Susan could do at her school, using echos on the playground wall to measure the speed of sound. Indicate what materials Susan would need, what measurements she will take, and what computations she will make.

(b) Four teams in Susan's class did the experiment you described. Each team got a different answer. Explain one reason why this might happen.

A: Outline of Experiment

Note: There are two variables for this item, one for each question, A and B.
Part A: Responses to this item should include the following three aspects:
i) Materials needed
ii) Description of the measurements of the distance and time.
iii) computation: Speed = distance/time (includes factor of 2x distance from source to wall)

Code	Response
	Correct Response
20	Response makes some reference to all three aspects, i, ii, iii.
29	Other acceptable responses such as using interference phenomena.
	Partial Response
10	Refers to two of the aspects, omits i.
11	Refers to two of the aspects, omits ii.
12	Refers to two of the aspects, omits iii.
13	Refers to all three aspects but with error in c, such as inconsistency, or a factor of 2 error in distance or time.
19	Other partially correct responses.
	Incorrect Response
70	Two of the aspects not adequately described.
79	Other unacceptable responses.
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

H19.

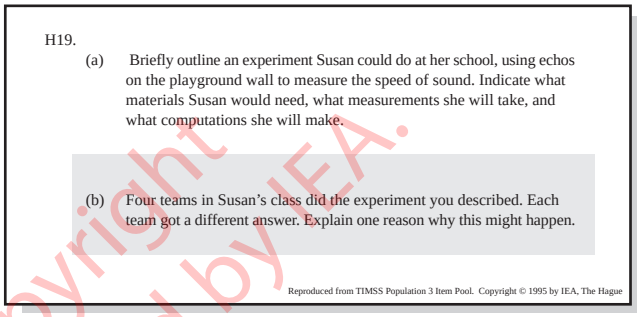
(a) Briefly outline an experiment Susan could do at her school, using echos on the playground wall to measure the speed of sound. Indicate what materials Susan would need, what measurements she will take, and what computations she will make.

(b) Four teams in Susan's class did the experiment you described. Each team got a different answer. Explain one reason why this might happen.

H-19b

Part b

Subject	Item Key	Content Category	Performance Expectation	International Average Percent of Students Responding Correctly	International Difficulty Index
Physics	next page	Wave Phenomena	Investigating the Natural World	45%	623



H19.

(a) Briefly outline an experiment Susan could do at her school, using echos on the playground wall to measure the speed of sound. Indicate what materials Susan would need, what measurements she will take, and what computations she will make.

(b) Four teams in Susan's class did the experiment you described. Each team got a different answer. Explain one reason why this might happen.

B: Why this might happen

Code	Response
	Correct Response
10	Acceptable reasons referring to measurement uncertainty/error, due to **equipment.** *Examples: a) Different answer due to uncertainty in the very short time interval.* *b) Different answer due to uncertainty in distance.* *c) A stopwatch is not the best equipment to measure short time intervals.*
11	Acceptable reasons referring to errors/uncertainty due to **students.** *Examples: a) Different answer due to calculation error.* *b) Different answer due to misreadings.* *c) Different answer due to different reaction time.*
19	Other acceptable reasons. *Examples: a) Different answer due to variation in wind.* *b) Different answer due to experimental error.*
	Incorrect Response
79	Any unacceptable reason. *Examples: a) Different answer due to different temperature.* *b) Different answer due to different frequencies.*
	Nonresponse
90	Crossed-out/erased, illegible, or impossible to interpret.
99	BLANK

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