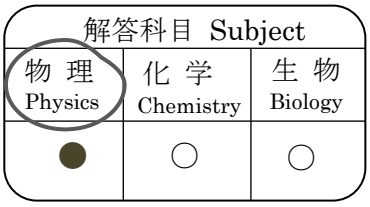
Physics

Marking Your Choice of Subject on the Answer Sheet

Choose two subjects from Physics, Chemistry, and Biology, and answer the questions for each. Use the front of the answer sheet for one subject and the back for the other.

As shown in the example on the right, if you answer the Physics questions, circle "Physics" and completely fill in the oval under the subject name.

＜Example＞



If you do not fill in the correct oval, your answers will not be graded.

Q1. As shown in Figure 1-1, a light spring with a natural length l is connected to a light, inextensible string 1 with length r, and both ends are fixed horizontally. Let point A be the end of the spring, point B be the end of the string, and point P be the junction where the spring and string are connected. The distance between points A and B is d.

Next, a small ball with mass M is suspended from point P using another light, inextensible string 2, and as shown in Figure 1-2, the spring stretches, and the ball comes to rest. At this point, the total length of the spring is L, the angle $\angle PAB=\alpha$, and the angle $\angle PBA=\beta$. The spring constant is k, and the acceleration due to gravity is g.

Let F represent the magnitude of the elastic force in the spring, T_1, the tension in string 1, and T_2 the tension in string 2. When the ball is at rest, the equation for horizontal equilibrium is given by [(a)], and the equation for vertical equilibrium is given by [(b)]. The elastic force in the spring can be expressed without using the natural length l as $F =$ [(c)], and $\sin\alpha =$ [(d)], $\cos\alpha =$ [(e)]. The mass of the ball can be expressed as $M=$[(f)].

Even if the mass of the ball increases, the spring will not stretch beyond a certain length. This maximum length is $L_{\max}$, which is [(g)].

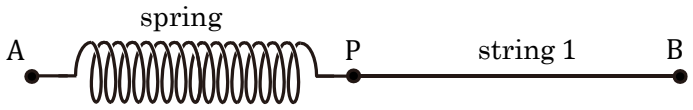


Figure 1-1

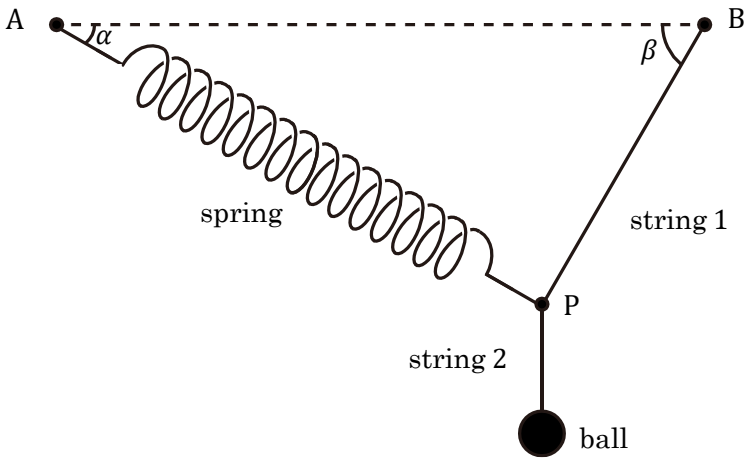


Figure 1-2

Choose the most appropriate answer from the options ① to ⑥ for (a) to (g).

Options for (a) 1

① $F = T_1$ ② $F = T_2$ ③ $T_1 = T_2$

④ $F\cos\alpha = T_1\cos\beta$ ⑤ $F\sin\alpha = T_1\sin\beta$ ⑥ $T_1\cos\alpha = T_2$

Options for (b) 2

① $F = T_1 + T_2$ ② $T_2 = F + T_1$

③ $T_1 = T_2$ ④ $F\cos\alpha = T_1\cos\beta + T_2$

⑤ $F\sin\alpha = T_1\sin\beta + T_2$ ⑥ $T_2 = F\sin\alpha + T_1\sin\beta$

Options for (c) 3

① kL ② $k(L-d)$ ③ $k(L-r)$

④ $k(d-r)$ ⑤ $k(L-d+r)$ ⑥ $k(L-d-r)$

Options for (d) 4

① $\dfrac{r\cos\beta}{L}$ ② $\dfrac{d-r\cos\beta}{L}$ ③ $\dfrac{d+r\cos\beta}{L}$

④ $\dfrac{r\sin\beta}{L}$ ⑤ $\dfrac{d-r\sin\beta}{L}$ ⑥ $\dfrac{d+r\sin\beta}{L}$

Options for (e) 5

① $\dfrac{r\cos\beta}{L}$ ② $\dfrac{d-r\cos\beta}{L}$ ③ $\dfrac{d+r\cos\beta}{L}$

④ $\dfrac{r\sin\beta}{L}$ ⑤ $\dfrac{d-r\sin\beta}{L}$ ⑥ $\dfrac{d+r\sin\beta}{L}$

Options for (f) 6

① $\frac{k}{gL}\tan\beta$ ② $\frac{k}{gL}\cos\beta$ ③ $\frac{k}{gL}\sin\beta$

④ $\frac{kd(L-d+r)}{gL}\tan\beta$ ⑤ $\frac{kd(L-d+r)}{gL}\cos\beta$ ⑥ $\frac{kd(L-d+r)}{gL}\sin\beta$

Options for (g) 7

① d ② r ③ $d-r$

④ $\sqrt{d^2-r^2}$ ⑤ $\sqrt{d^2+r^2}$ ⑥ $\sqrt{dr}$

Q2. As shown in Figure 2-1, the y-axis is set in the upward vertical direction, with a cylinder and piston arranged. A frictionless piston with a cross-sectional area of S [m^2] contains an ideal gas of monoatomic molecules, n [mol], inside the cylinder. At this point, the volume inside the cylinder is V_0 [m^3], and the pressure is $\frac{1}{2}P_0$ [Pa]. Let the atmospheric pressure near the cylinder be P_0 [Pa], and the gravitational acceleration be g [m/s^2]. The mass of the piston is [(a)] [kg].

An experiment was conducted where the cylinder is slowly rotated 180° around its axis, as shown in Figure 2-2.

First, assume the piston and cylinder conduct heat well, and the temperature of the gas inside the cylinder equals the atmospheric temperature. After the rotation, the pressure of the gas inside the cylinder is [(b)] [Pa], and the volume is [(c)] [m^3]. During the process of rotating the cylinder 180°, [(d)].

Next, the piston and cylinder are replaced with ones made of insulating material, and the same experiment is conducted. Assume that the initial temperature of the gas inside the cylinder is equal to the atmospheric temperature. During the 180° rotation, since [(e)], the temperature of the gas inside the cylinder becomes [(f)].

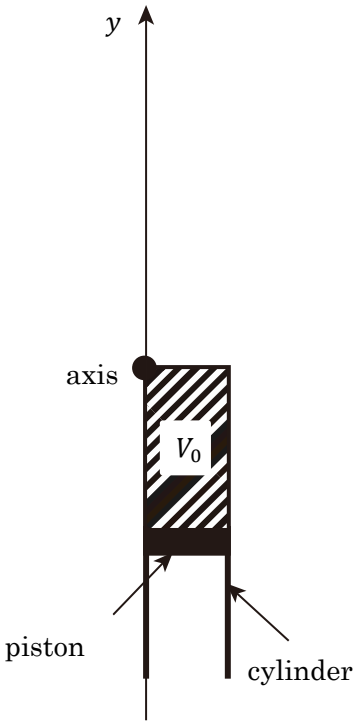


Figure 2-1

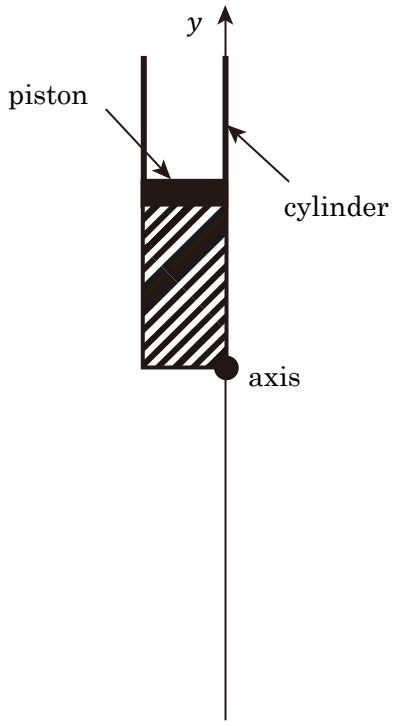


Figure 2-2

Choose the most appropriate answer from the options ① to ⑥ for [(a)] to [(c)].

Choose the most appropriate answer from the options ① to ③ for [(d)] to [(f)].

Options for (a) 8

① 0 ② $\frac{P_0S}{3g}$ ③ $\frac{P_0S}{2g}$

④ $\frac{P_0S}{g}$ ⑤ $\frac{3P_0S}{2g}$ ⑥ $\frac{2P_0S}{g}$

Options for (b) 9

① $\frac{P_0}{4}$ ② $\frac{P_0}{2}$ ③ P_0

④ $\frac{3P_0}{2}$ ⑤ $2P_0$ ⑥ $4P_0$

Options for (c) 10

① $\frac{1}{5}V_0$ ② $\frac{1}{4}V_0$ ③ $\frac{1}{3}V_0$

④ $\frac{1}{2}V_0$ ⑤ V_0 ⑥ $3V_0$

Options for (d) 11

① heat moves from inside the cylinder to the outside

② heat moves from outside to inside the cylinder

③ heat does not move

Options for (e) 12

① heat moves from inside the cylinder to the outside

② heat moves from outside to inside the cylinder

③ heat does not move

Options for (f) 13

① equal to the temperature of the atmosphere

② higher than the temperature of the atmosphere

③ lower than the temperature of the atmosphere

Q3. As shown in Figure 3-1, a sound source emitting a sound wave with a frequency f_0 is moving along a straight path at a speed v. An observer is located at point A, ahead of the source along this path. Let the speed of sound in the air be V, and assume the speed of the sound source v is less than the speed of sound V.

The wavelength of the sound wave in front of the sound source is [(a)]. When the observer is moving in the same direction as the sound source at speed v ($v < V$) from point A, the frequency of the sound heard by the observer is [(b)].

Now, consider the case where the observer is at point P, at a distance l from the path of the sound source, as shown in Figure 3-2. Here, the relationship between the speed of the sound source and the speed of sound is $V = 2v$. At point Q, where the angle between the straight line connecting the sound source and point P and the direction of motion of the sound source is θ, consider the sound wave emitted by the sound source. The velocity component of the sound source in the direction toward point P is [(c)], and the sound wave emitted at point Q is observed at point P with a frequency of [(d)].

Finally, consider the case where the sound source approaches from a far distance and then moves away. The possible range of frequencies f observed at point P is [(e)] $< f <$ [(f)].



Figure 3-1

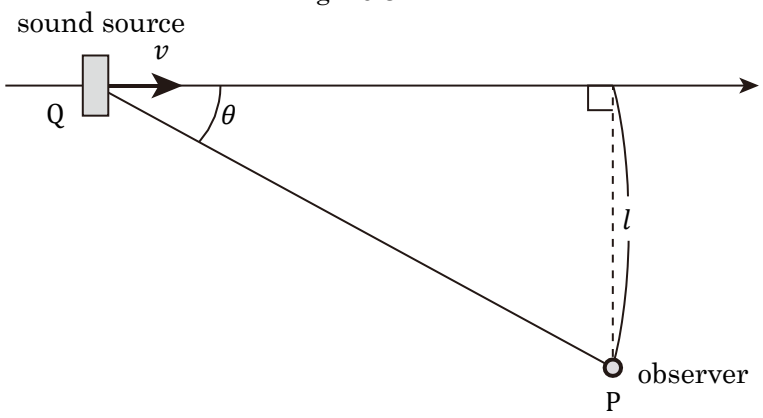


Figure 3-2

Choose the most appropriate answer from the options ① to ⑥ for [(a)] to [(f)].

Options for (a) 14

① $\frac{v-V}{f_0}$ ② $\frac{V+v}{f_0}$ ③ $\frac{V-v}{f_0}$

④ $\frac{V}{f_0}$ ⑤ $\frac{v}{f_0}$ ⑥ $\frac{2v}{f_0}$

Options for (b) 15

① $\frac{vf_0}{v-V}$ ② $\frac{V-v}{v-V}f_0$ ③ $\frac{v}{V-v}f_0$

④ f_0 ⑤ $\frac{V+v}{V-v}f_0$ ⑥ $\frac{V}{V-v}f_0$

Options for (c) 16

① $v\sin\theta$ ② $v\cos\theta$ ③ $v\tan\theta$

④ $\frac{1}{v\sin\theta}$ ⑤ $\frac{1}{v\cos\theta}$ ⑥ $\frac{1}{v\tan\theta}$

Options for (d) 17

① $\frac{f_0}{1-\cos\theta}$ ② $\frac{f_0}{2-\cos\theta}$ ③ $\frac{2f_0}{2-\cos\theta}$

④ $\frac{f_0}{1+\cos\theta}$ ⑤ $\frac{f_0}{2+\cos\theta}$ ⑥ $\frac{2f_0}{2+\cos\theta}$

Options for (e) 18

① 0 ② $\frac{1}{2}f_0$ ③ $\frac{2}{3}f_0$

④ f_0 ⑤ $2f_0$ ⑥ $4f_0$

Options for (f) 19

① $\frac{1}{3}f_0$ ② $\frac{1}{2}f_0$ ③ f_0

④ $\frac{3}{2}f_0$ ⑤ $2f_0$ ⑥ $5f_0$

Q4. As shown in Figure 4-1, a coil A with N_A turns and length l, and a coil B with N_B turns and length l, are wound around an iron core with a cross-sectional area S. Coil A is connected in series with a power supply and a resistor R_A with resistance value R. Similarly, coil B is connected in series with a resistor R_B with resistance value R. The permeability of the iron core is μ, and the iron core has no power losses. Additionally, the magnetic flux penetrating the iron core does not leak outside, and the magnetic flux passing through coils A and B is the same.

When the voltage drop across resistor R_A is V, the current flowing through R_A is given by [(a)]. The self-inductance L of coil A is given by $L =$ [(b)], and the mutual inductance M between coils A and B is given by $M =$ [(c)]. The current through resistor R_A increases by ΔI over a time interval Δt, where $\Delta I > 0$. At this time, the magnitude of the self-induced electromotive force in coil A is given by [(d)], and the magnitude of the mutual-induced electromotive force generated in coil B is given by [(e)].

As shown in Figure 4-2, a triangular wave current I, with a period T and amplitude I_0, is passed through coil A. The maximum value of the induced electromotive force V_B generated in coil B is given by [(f)], and the graph representing one cycle of the time variation of V_B is [(g)]. The direction of the current as indicated by the arrow in Figure 4-1 is taken as the positive direction, and the electromotive force that drives the current in the direction of the arrow is considered positive.

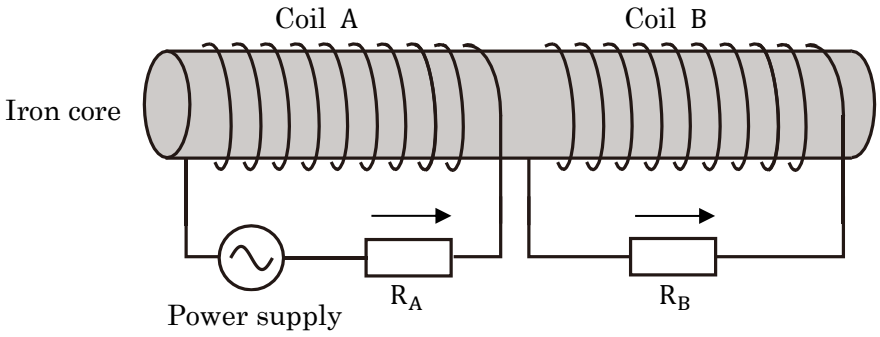


Figure 4-1

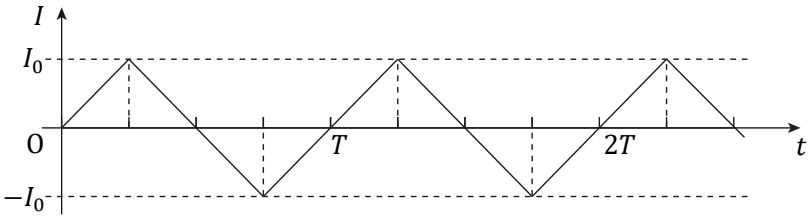


Figure 4-2

Choose the most appropriate option for each of (a) to (g) from the following options ① to ⑥.

Options for (a) 20

① RV ② $\frac{R}{V}$ ③ $\frac{\mu N_{\mathrm{A}}}{V}$

④ $\mu N_{\mathrm{A}} V$ ⑤ $\frac{V}{R}$ ⑥ $\frac{V}{\mu N_{\mathrm{A}}}$

Options for (b) 21

① $\frac{\mu N_{\mathrm{A}}}{S}$ ② $\frac{\mu N_{\mathrm{A}}}{l}$ ③ $\frac{\mu {N_{\mathrm{A}}}^2}{S}$

④ $\frac{\mu {N_{\mathrm{A}}}^2}{l}$ ⑤ $\frac{\mu {N_{\mathrm{A}}}^2 l}{S}$ ⑥ $\frac{\mu {N_{\mathrm{A}}}^2 S}{l}$

Options for (c) 22

① $\frac{\mu N_{\mathrm{B}}}{S}$ ② $\frac{\mu N_{\mathrm{B}}}{l}$ ③ $\frac{\mu {N_{\mathrm{B}}}^2}{S}$

④ $\frac{\mu {N_{\mathrm{B}}}^2}{l}$ ⑤ $\frac{\mu N_{\mathrm{A}} N_{\mathrm{B}} l}{S}$ ⑥ $\frac{\mu N_{\mathrm{A}} N_{\mathrm{B}} S}{l}$

Options for (d) 23

① $L\Delta t$ ② $L\Delta I$ ③ $\frac{L\Delta t}{\Delta I}$

④ $\frac{L\Delta I}{\Delta t}$ ⑤ $\frac{\Delta t}{L\Delta I}$ ⑥ $\frac{\Delta t}{L\Delta I}$

Options for (e) 24

① $M\Delta t$ ② $M\Delta I$ ③ $\dfrac{M\Delta t}{\Delta I}$

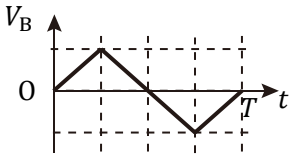
④ $\dfrac{M\Delta I}{\Delta t}$ ⑤ $\dfrac{\Delta t}{M\Delta I}$ ⑥ $\dfrac{\Delta t}{M\Delta I}$

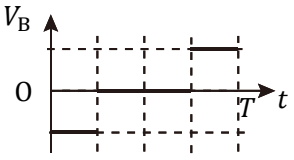
Options for (f) 25

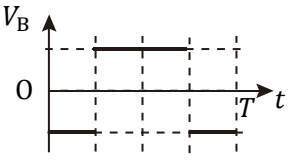
① $\dfrac{LI_0}{T}$ ② $\dfrac{2LI_0}{T}$ ③ $\dfrac{4LI_0}{T}$

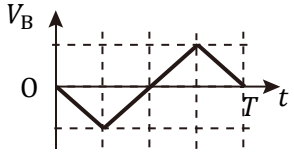
④ $\dfrac{MI_0}{T}$ ⑤ $\dfrac{2MI_0}{T}$ ⑥ $\dfrac{4MI_0}{T}$

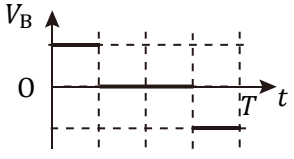
Options for (g) 26

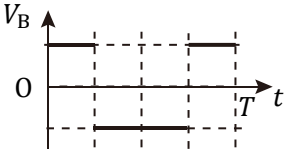
①


②


③


④


⑤


⑥


Q5. In Bohr's model of the hydrogen atom, it is assumed that the electron moves in a circular orbit around a stationary proton. Let the radius of the circular orbit is r, and the velocity of the electron is v, and the mass of the electron is m. The magnitude of the centripetal force of the circular motion is given by [(a)]. Let e be the elementary charge and k be the proportionality constant of Coulomb's law. The magnitude of the Coulomb force acting between the proton and the electron is given by [(b)].

The kinetic energy of the electron moving in a circular orbit can be expressed using the radius r as [(c)]. Taking the potential energy of the electron due to the Coulomb force, with the reference point set at infinity, the potential energy is given by [(d)] Therefore, the total energy, which is the sum of kinetic and potential energies, for the electron in circular motion is given by [(e)].

Given the Planck constant h, the wavelength of the matter wave of the electron moving with velocity v is given by [(f)]. When the length of the circular orbit of the electron in the hydrogen atom matches n times (where n is a positive integer) the wavelength of the matter wave, a stable orbit is formed, and the radius of the circular orbit r can be determined by [(g)].

Choose the most appropriate items to fill in [(a)] to [(g)] from the following options ① to ⑥, selecting one for each.

Options for [(a)] [27]

① mrv^2 ② $\frac{mv^2}{2r}$ ③ $\frac{mv^2}{2r^2}$

④ $2mrv^2$ ⑤ $\frac{mv^2}{r}$ ⑥ $\frac{mv^2}{r^2}$

Options for [(b)] [28]

① $\frac{ke}{2r}$ ② $\frac{ke^2}{2r}$ ③ $\frac{ke^2}{2r^2}$

④ $\frac{ke}{r}$ ⑤ $\frac{ke^2}{r}$ ⑥ $\frac{ke^2}{r^2}$

Options for (c) 29

① $\frac{ke}{2r}$ ② $\frac{ke^2}{2r}$ ③ $\frac{ke^2}{2r^2}$

④ $\frac{ke}{r}$ ⑤ $\frac{ke^2}{r}$ ⑥ $\frac{ke^2}{r^2}$

Options for (d) 30

① $-\frac{ke}{2r}$ ② $-\frac{ke^2}{2r}$ ③ $-\frac{ke^2}{2r^2}$

④ $-\frac{ke}{r}$ ⑤ $-\frac{ke^2}{r}$ ⑥ $-\frac{ke^2}{r^2}$

Options for (e) 31

① $-\frac{ke}{2r}$ ② $-\frac{ke^2}{2r}$ ③ $-\frac{ke^2}{2r^2}$

④ $-\frac{ke}{r}$ ⑤ $-\frac{ke^2}{r}$ ⑥ $-\frac{ke^2}{r^2}$

Options for (f) 32

① hmv ② $\frac{mv}{h}$ ③ $\frac{mv^2}{h}$

④ hmv^2 ⑤ $\frac{h}{mv}$ ⑥ $\frac{h}{mv^2}$

Options for (g) 33

① $\frac{\pi^2 kme^2}{h^2}n$ ② $\frac{4\pi^2 kme^2}{h^2}n$ ③ $\frac{4\pi^2 kme^2}{h^2}n^2$

④ $\frac{h^2}{\pi^2 kme^2}n$ ⑤ $\frac{h^2}{4\pi^2 kme^2}n$ ⑥ $\frac{h^2}{4\pi^2 kme^2}n^2$

End of Physics questions. Leave the answer spaces 34 ~ 75 blank.
Please check once more that you have properly marked the name of your subject as "Physics" on your answer sheet.

Do not take this question booklet out of the room.