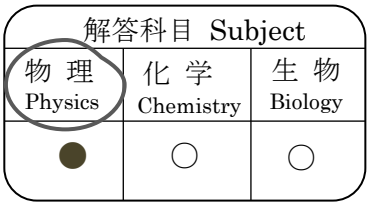
Physics

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 horizontal surface at a height h above the floor is smoothly connected to the floor via a curved surface. Object A, with mass m, is initially at rest on the floor. At the right edge of the horizontal surface, object B, also with mass m, is suspended vertically from above by a light, inextensible string of length l, such that it is in contact with the horizontal surface. When an initial velocity V is given to object A in the rightward horizontal direction, object A moves without leaving the curved surface and collides with object B. After the collision, object B begins to move along a circular arc. The string does not slacken or break. Assume the acceleration due to gravity is g, and friction between the objects and surfaces is negligible. Additionally, consider the positive direction to be rightward along the floor.

The condition for object A to reach the position of object B is $V >$ (a).

The collision between object A and object B is elastic. If the velocity of object A just before the collision is v_0, then the velocity of object A immediately after the collision is $v_A =$ (b), and the velocity of object B is $v_B =$ (c).

As shown in Figure 1-2, when the angle between the string suspending object B and the vertical is θ, the forces acting on object B are as depicted in (d). The speed of object B at this point, expressed in terms of its speed $|v_B|$ immediately after the collision, is $v =$ (e). At the moment object B reaches its highest point, the angle between the string and the vertical is θ_0. The tension in the string at this point is (f). Note that $\theta_0 < 90°$.

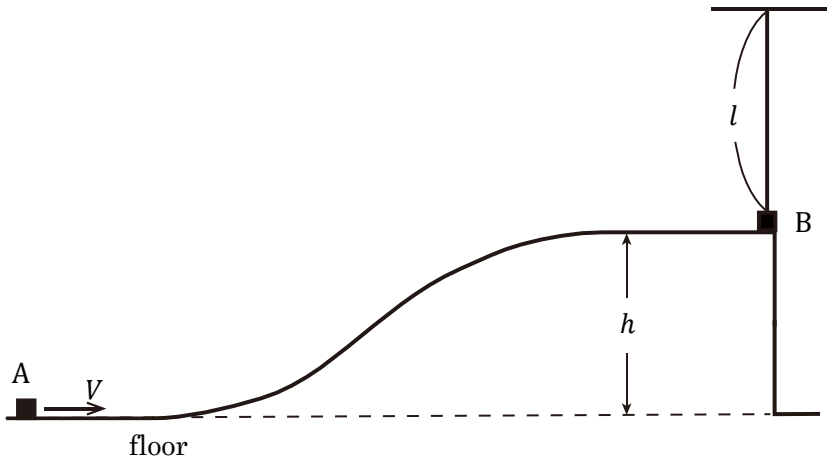


Fig. 1-1

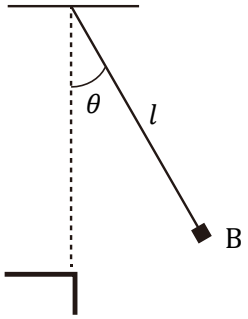


Fig. 1-2

Choose the most appropriate items to fill in blanks (a) to (f) from options ① to ⑥, selecting one for each.

Options for (a) 1

① $\frac{\sqrt{gh}}{2}$ ② $\sqrt{\frac{gh}{2}}$ ③ $\sqrt{gh}$

④ $\sqrt{2gh}$ ⑤ $\sqrt{3gh}$ ⑥ $2\sqrt{gh}$

Options for (b) 2

① $-v_0$ ② $-\frac{1}{2}v_0$ ③ 0

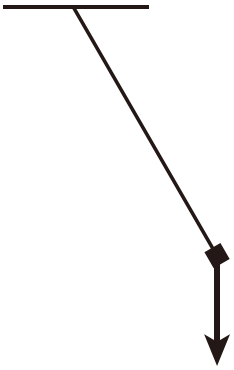
④ $\frac{1}{2}v_0$ ⑤ v_0 ⑥ $2v_0$

Options for (c) 3

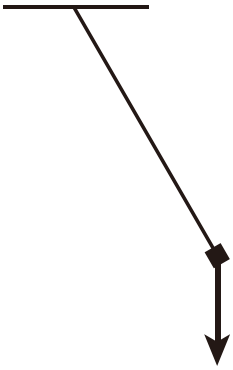
① $-v_0$ ② $-\frac{1}{2}v_0$ ③ 0

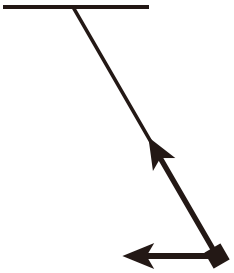
④ $\frac{1}{2}v_0$ ⑤ v_0 ⑥ $2v_0$

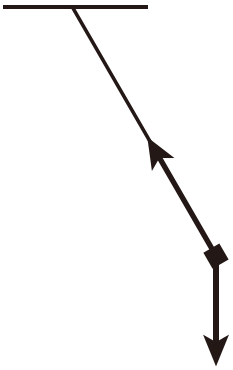
Options for (d) 4

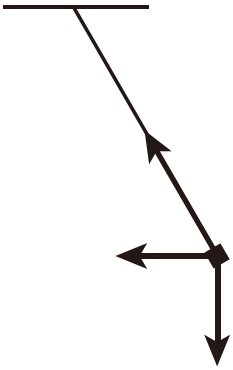
① 

② 

③ 

④ 

⑤ 

⑥ 

Options for (e) 5

① $|v_{\mathrm{B}}|$

② $\sqrt{|v_{\mathrm{B}}|^2 - 2gl\cos\theta}$

③ $\sqrt{|v_{\mathrm{B}}|^2 - 2gl\,(1-\cos\theta)}$

④ $\dfrac{|v_{\mathrm{B}}|}{2}$

⑤ $\sqrt{\dfrac{|v_{\mathrm{B}}|^2}{4} - 2gl\cos\theta}$

⑥ $\sqrt{\dfrac{|v_{\mathrm{B}}|^2}{4} - 2gl\,(1-\cos\theta)}$

Options for (f) 6

① mg

② $mg\cos\theta_0$

③ $mg\sin\theta_0$

④ $\dfrac{1}{2}mg$

⑤ $\dfrac{1}{2}mg\cos\theta_0$

⑥ $\dfrac{1}{2}mg\sin\theta_0$

Q2. As shown in Figure 2, an ideal gas of monatomic molecules is slowly transformed from state A to state B, state C, state D, and then back to state A in the direction of the arrows. At state A, the pressure is $2P_0$ [Pa], the temperature is T_0 [K]], and the volume is V_A [m^3]. The molar heat capacity at constant volume is denoted by $\frac{3}{2}R$[J/(mol · K)].

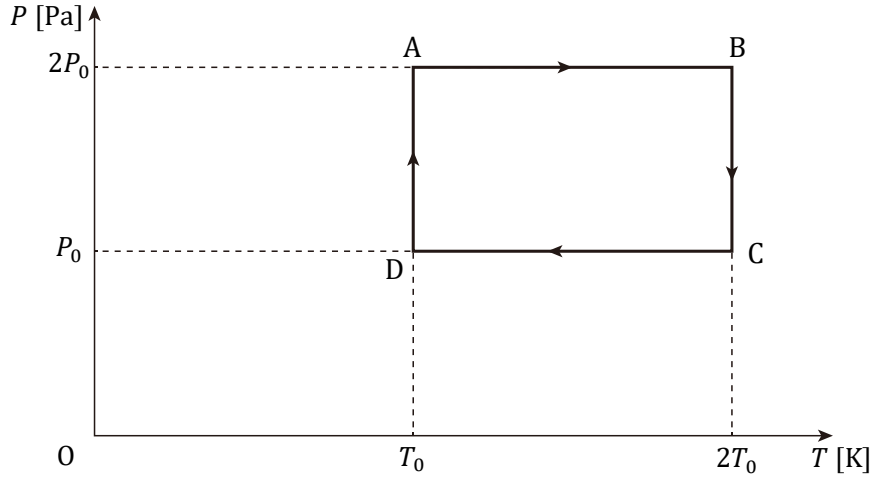


Fig. 2

The amount of substance of this ideal gas is [(a)] [mol], and the volume at state D is [(b)] [m³].

The work done by the gas on the external surroundings during the process from state A to state B is [(c)] [J]. Also, the heat added to the gas during the process from state A to state B is [(d)] [J].

The graph of pressure P [Pa] versus volume V [m^3] for this process is represented by [(e)].

Now, consider changing the gas from a monatomic molecule to a diatomic molecule with the same amount of substance. The gas undergoes a cycle of state changes from state A to state B, state C, state D and back to state A, under the same conditions of pressure and temperature as in Figure 2. In this case, compared to the monatomic molecule scenario, the work done by the gas on the external surroundings is [(f)]. Additionally, the heat added to the gas is [(g)], and the thermal efficiency for this cycle is [(h)]. Assume that the molar heat capacity at constant volume for the diatomic ideal gas is greater than that for the monatomic ideal gas.

Choose the most appropriate items to fill in blanks (a) to (e) from options ① to ⑥, selecting one for each.

Choose the most appropriate items to fill in blanks (f) to (h) from options ① to ③, selecting one for each.

Options for (a) 7

① $\frac{P_0V_A}{T_0}$ ② $\frac{P_0V_A}{RT_0}$ ③ $\frac{V_A}{RT_0}$

④ $\frac{2P_0V_A}{T_0}$ ⑤ $\frac{2P_0V_A}{RT_0}$ ⑥ $\frac{2V_A}{RT_0}$

Options for (b) 8

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

④ $2V_A$ ⑤ $3V_A$ ⑥ $4V_A$

Options for (c) 9

① $\frac{P_0V_A}{4}$ ② $\frac{P_0V_A}{2}$ ③ 0

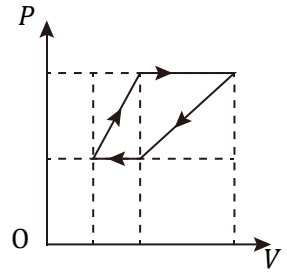
④ P_0V_A ⑤ $2P_0V_A$ ⑥ $5P_0V_A$

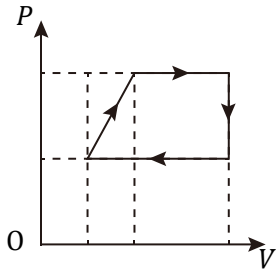
Options for (d) 10

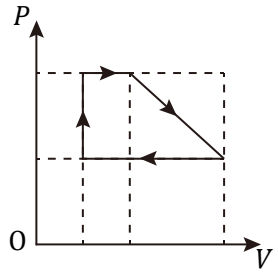
① $\frac{P_0V_A}{4}$ ② $\frac{P_0V_A}{2}$ ③ 0

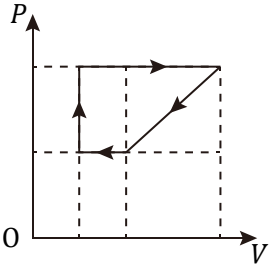
④ P_0V_A ⑤ $2P_0V_A$ ⑥ $5P_0V_A$

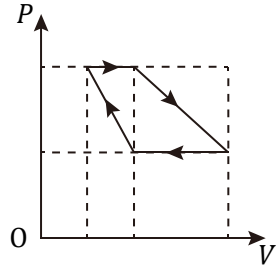
Options for (e) 11

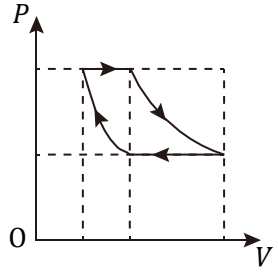
① 

② 

③ 

④ 

⑤ 

⑥ 

Options for (f) 12

① Remains the same ② Increases ③ Decreases

Options for (g) 13

① Remains the same ② Increases ③ Decreases

Options for (h) 14

① Remains the same ② Increases ③ Decreases

Q3. As shown in Figure 3, one end of a string is fixed at point P, and a weight is suspended through a pulley at the other end. A movable support is placed between point P and the pulley, and a stationary wave is generated by plucking the string segment PQ. Let the gravitational acceleration be g [m/s^2], the tension in the string be S [N], and the linear density of the string be ρ [kg/m]. The speed of the wave traveling through the string is given by $v = \sqrt{\frac{S}{\rho}}$ [m/s] formula.

A weight with a mass m [kg] is suspended on a string with a linear density ρ_1 [kg/m], and when the distance between points P and Q is set to L [m] and the string is plucked, a stationary wave of fundamental frequency f_1 [Hz] is generated. The value of $f_1 =$ (a) [Hz].

Next, a tuning fork vibrating at a frequency of 440 Hz was sounded near the string, and a beat with a period of 0.5 seconds was heard. When a tuning fork vibrating at a frequency of 444 Hz was sounded, the beat period became shorter than 0.5 seconds. Therefore, $f_1 =$ (b) [Hz].

Next, while keeping the distance between P and Q at L [m], the mass of the weight was varied, and a stationary wave of the fundamental frequency was generated on the string PQ. The graph showing the relationship between the mass of the weight and the frequency of the string vibration is shown in (c). When the mass of the weight is changed to $\frac{9}{4}m$ [kg], the fundamental frequency of the vibration generated in the string PQ becomes f_2 [Hz], where $f_2 = f_1 \times$ (d) [Hz].

Finally, without changing the mass of the weight m [kg] or the distance between points P P and Q L [m], the string was replaced. At this time, the fundamental frequency of the vibration generated in the string PQ became 0.5 times f_1. The linear density of the new string is (e) times the linear density of the original string.

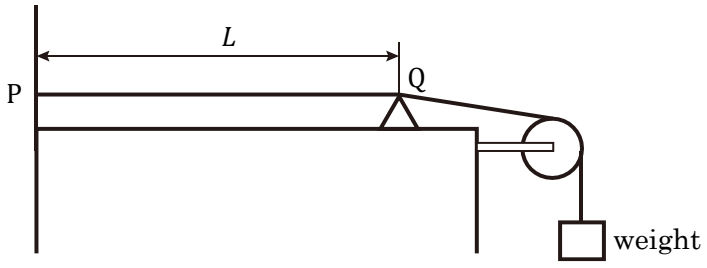


Fig. 3

Choose the most appropriate items to fill in blanks (a) to (e) from options ① to ⑥, selecting one for each.

Options for (a) 15

① $\frac{1}{2L}\sqrt{\frac{mg}{\rho_1}}$ ② $\frac{1}{L}\sqrt{\frac{mg}{\rho_1}}$ ③ $\frac{2}{L}\sqrt{\frac{mg}{\rho_1}}$

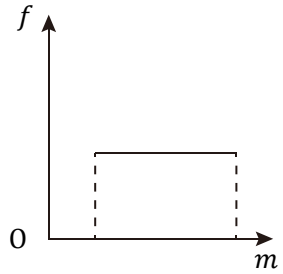
④ $\frac{1}{2L}\sqrt{\frac{\rho_1}{mg}}$ ⑤ $\frac{1}{L}\sqrt{\frac{\rho_1}{mg}}$ ⑥ $\frac{2}{L}\sqrt{\frac{\rho_1}{mg}}$

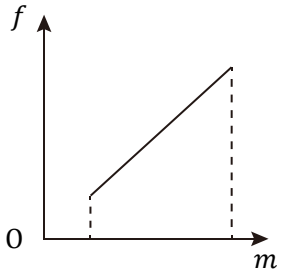
Options for (b) 16

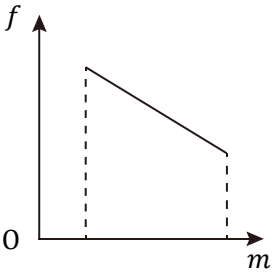
① 438 ② 438.5 ③ 439

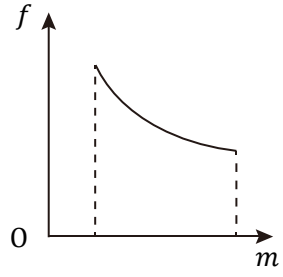
④ 439.5 ⑤ 440.5 ⑥ 441

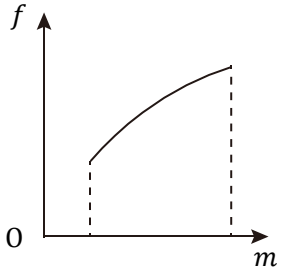
Options for (c) 17

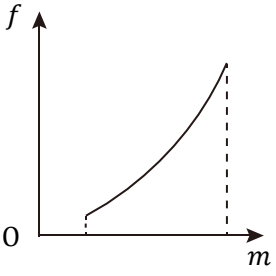
①


②


③


④


⑤


⑥


Options for (d) 18

① $\frac{4}{9}$ ② $\frac{2}{3}$ ③ $\frac{3}{4}$

④ $\frac{4}{3}$ ⑤ $\frac{3}{2}$ ⑥ $\frac{9}{4}$

Options for (e) 19

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

④ $\sqrt{2}$ ⑤ 2 ⑥ 4

Q4. As shown in Figure 4-1, positive charges of quantity Q are fixed at points A$(-a,\ 0)$ and B$(a,\ 0)$ on the xy-plane with the origin O$(0,\ 0)$. Here, $a > 0$. The curve in Figure 4-2 represents the equipotential surfaces at this time, and it is assumed that the potential difference between adjacent equipotential surfaces is constant. Let the proportionality constant of Coulomb's law be k.

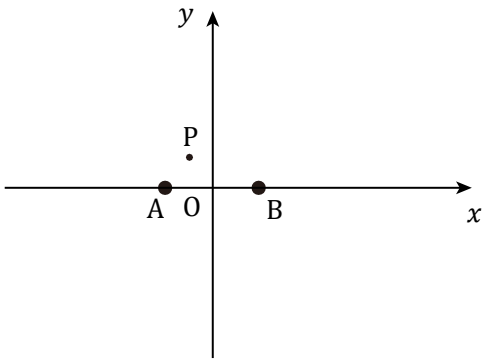


Figure 4-1

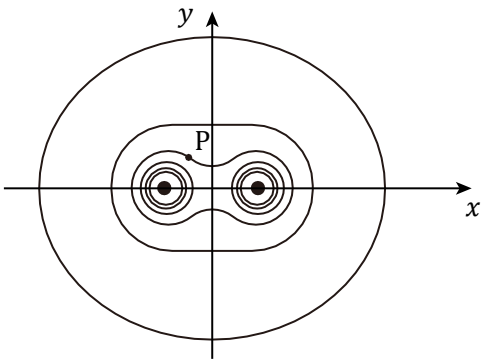


Figure 4-2

The electric field lines passing through point P in Figure 4-2 are represented by [(a)], and the change in potential V along the x-axis is represented by [(b)]. Here, the potential at infinity is set to 0. The potential at the origin O is $V_O =$ [(c)]. When a point charge with charge $q\ (q > 0)$ and mass m is placed quietly at the origin O and slightly displaced in the y-axis direction, it begins to move under the influence of the electric field. When the point charge has moved sufficiently far away, its speed will be [(d)].

When a point charge with charge $q\ (q > 0)$ and mass m is placed at point $(x,\ 0)$, it begins to move under the influence of the electric field towards the origin O. The magnitude of the force exerted on the point charge by the electric field is [(e)], assuming $0 < x < a$.

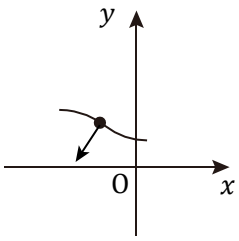
Consider the case where $|x| \ll a$. The magnitude of the force exerted on the point charge by the electric field when it starts moving can be approximated as [(f)], and the time it takes for the point charge, which was initially stationary, to reach the origin O for the first time after it starts moving can be approximated as [(g)].

If necessary, you may use the approximation formula $(1+\delta)^n \fallingdotseq 1 + n\delta$ for $|\delta| \ll 1$ (where n is an integer).

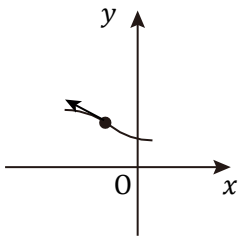
Choose the most appropriate items to fill in blanks [(a)] to [(g)] from options ① to ⑥, selecting one for each.

Options for (a) 20

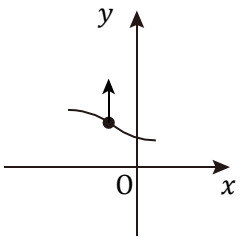
①



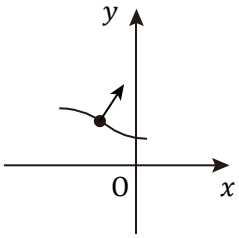
②



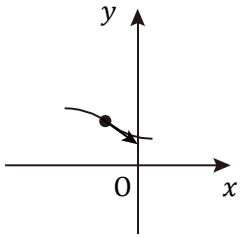
③



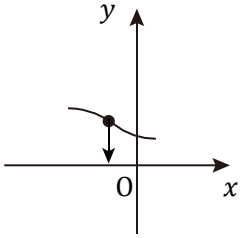
④



⑤

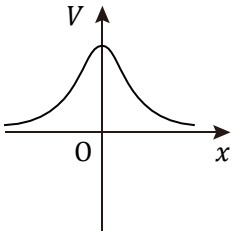


⑥

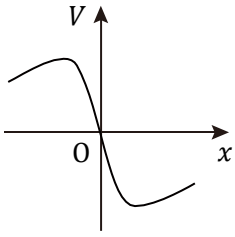


Options for (b) 21

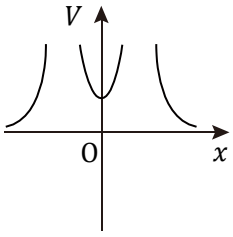
①



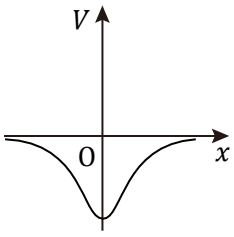
②



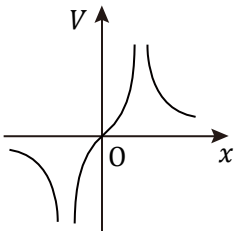
③



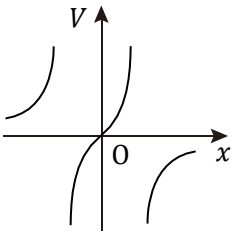
④



⑤



⑥



Options for (c) 22

① $\frac{kQ}{a}$ ② $\frac{Q}{ka}$ ③ $\frac{kQ}{a^2}$

④ $\frac{2kQ}{a}$ ⑤ $\frac{2Q}{ka}$ ⑥ $\frac{2kQ}{a^2}$

Options for (d) 23

① $\sqrt{qV_0}$ ② $\sqrt{\frac{QV_0}{m}}$ ③ $\sqrt{\frac{qV_0}{m}}$

④ $\sqrt{2qV_0}$ ⑤ $\sqrt{\frac{2QV_0}{m}}$ ⑥ $\sqrt{\frac{2qV_0}{m}}$

Options for (e) 24

① $kqQ\frac{1}{(a-x)^2}$ ② $kqQ\frac{1}{(a+x)^2}$ ③ $kqQ\left\{\frac{1}{(a-x)^2}-\frac{1}{(a+x)^2}\right\}$

④ $kqQ\frac{1}{a-x}$ ⑤ $kqQ\frac{1}{a+x}$ ⑥ $kqQ\left\{\frac{1}{a-x}-\frac{1}{a+x}\right\}$

Options for (f) 25

① $\frac{2kqQ|x|}{a}$ ② $\frac{2kqQ|x|}{a^2}$ ③ $\frac{2kqQ|x|}{a^3}$

④ $\frac{4kqQ|x|}{a}$ ⑤ $\frac{4kqQ|x|}{a^2}$ ⑥ $\frac{4kqQ|x|}{a^3}$

Options for (g) 26

① $\frac{\pi a}{2}\sqrt{\frac{am}{k}}$ ② $\frac{\pi a}{2}\sqrt{\frac{m}{kqQ}}$ ③ $\frac{\pi a}{2}\sqrt{\frac{am}{kqQ}}$

④ $\frac{\pi a}{2}\sqrt{\frac{am}{k}}$ ⑤ $\frac{\pi a}{4}\sqrt{\frac{m}{kqQ}}$ ⑥ $\frac{\pi a}{4}\sqrt{\frac{am}{kqQ}}$

Q5. Using a vacuum tube with metal electrodes A and B, along with a light source and power supply, the following experiment was conducted. When monochromatic light is irradiated on electrode A inside the vacuum tube, and a voltage is applied so that electrode B becomes positively charged, a current flows between electrodes A and B. This indicates that electrons have been emitted from electrodes A and have reached electrode B. This phenomenon is called [(a)]. However, when a voltage is applied so that electrodes A is positively charged, the current ceases at a certain voltage V_C [V]. This voltage is called the stopping voltage. When the wavelength λ [m] of the monochromatic light is varied, the stopping voltage V_C changes as shown in Table 5.

Table 5

λ [m]	8.9×10^{-7}	6.3×10^{-7}	5.2×10^{-7}	3.9×10^{-7}
V_C [V]	1.12	1.70	2.12	2.92

Here, let the speed of light be c [m/s], the elementary charge of an electron be e [C], Planck's constant be h [J · s], and the work function of the metal of electrode A be W [J]. The relationship between the wavelength λ and frequency ν [Hz] of the monochromatic light is given by $\nu =$ [(b)] [Hz]. The maximum kinetic energy of the electrons emitted from electrode A when irradiated with monochromatic light of frequency ν is given by [(c)] [J]. From the relationship with V_C, the equation $V_C =$ [(d)] [V] is obtained. Given that the speed of light is $c = 3.0 \times 10^8$ [m/s] and the elementary charge of an electron is $e = 1.6 \times 10^{-19}$ [C], h can be determined as [(e)] [J · s], and W as [(f)] [J].

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

Options for [(a)] 27

① Compton effect ② Tunneling effect ③ Photoelectric effect

④ Doppler effect ⑤ Bauschinger effect ⑥ Kondo effect

Options for (b) 28

① $\frac{\lambda}{c}$ ② $\frac{\lambda}{h}$ ③ $\frac{\lambda}{e}$

④ $\frac{c}{\lambda}$ ⑤ $\frac{h}{\lambda}$ ⑥ $\frac{e}{\lambda}$

Options for (c) 29

① $h\nu - W$ ② $c\nu - W$ ③ $e\nu - W$

④ $W - h\nu$ ⑤ $W - c\nu$ ⑥ $W - e\nu$

Options for (d) 30

① $\frac{h}{e}\nu$ ② $\frac{W}{e}$ ③ $\frac{h}{e}\nu + \frac{W}{e}$

④ $\frac{h}{e}\nu - \frac{W}{e}$ ⑤ $\frac{W}{e} - \frac{h}{e}\nu$ ⑥ 0

Options for (e) 31

① 2.4×10^{-34} ② 6.7×10^{-34} ③ 9.6×10^{-34}

④ 2.4×10^{-21} ⑤ 6.7×10^{-21} ⑥ 9.6×10^{-21}

Options for (f) 32

① 1.4×10^{-28} ② 4.6×10^{-28} ③ 8.3×10^{-28}

④ 1.4×10^{-20} ⑤ 4.6×10^{-20} ⑥ 8.3×10^{-20}

End of Physics questions. Leave the answer spaces 33 ~ 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.