TASHKENT UNIVERSITY OF TECHNOLOGY

Physics

Variant 6

CONSTRUCTOR KNOWLEDGE

Part 1

Physics. Questions 1–10

Write your answer on Answer Sheet No. 1 to the right of the corresponding question number. Where applicable, include the units of measurement. If you need to correct an answer, cross out the incorrect one, enter the question number in the table below, and write the correct answer in the field to the right.

1. While walking around Samarkand, Mark walked 5 km south, then 5 km west, and then another 7 km south. What distance did Mark move from the starting point?
2. The Venus spacecraft with a mass of 220 kg descends at a constant speed in the atmosphere of Venus. The gravitational acceleration on Venus is 8.9 m/s^2. Find the air resistance force acting on the spacecraft.
3. During the laboratory experiment, the pressure of xenon dropped two times, while the concentration of gas molecules dropped 4 times. By how many times did the absolute temperature of xenon increase as a result?
4. 63 calories of heat heated 0.6 g of water from zero degrees Celsius to the boiling point. Use these data to calculate how many joules are in 1 calorie. The specific heat capacity of water is 4200 J/(kg · °C).
5. A point charge $q = +12$ nC is placed in a uniform horizontal electric field $E = 40$ kV/m. Find the magnitude of the total electric field at a point $h = 6.0$ cm directly above the charge.
6. The voltage across a lamp depends on the current through it as $V = \alpha I^2$, where $\alpha = 2.0$ V/A^2. Find the power dissipated by the lamp for $I = 3.0$ A.
7. A simple pendulum oscillates with a period of 2 s. A small adhesive weight of the same mass is carefully stuck to the bottom of its bob in such a way that the oscillations are not disturbed. Find the new frequency of the pendulum.
8. Sebastian measured the sine of the critical angle for total internal reflection at the diamond–air interface and got 0.4. Use these data to find the refractive index of this diamond. Take the refractive index of air to be 1. Give your answer as a decimal fraction.
9. The transition from $n = 4$ to $n = 2$ corresponds to an energy of 2,07 eV. Determine the frequency of this photon.
10. A radioactive nucleus undergoes α-decay. How do its charge number and mass number change?
    Record two digits in the answer sheet: first for charge, second for mass number.
    Use: 1 = *increases*, 2 = *decreases*, 3 = *stays the same.*

Part 2

Physics. Questions 11–14

Use Answer Sheets No. 2 to write your solutions and answers to questions 11–14. Write your solution as completely and in as much detail as possible. Remember that even if you are unable to solve the problem completely, you may still receive some points for significant progress according to the marking criteria.

11. (2 points) A 1 kg body moves along a horizontal surface under the action of a 10 N force. This force is directed downward at an angle of 30° to the horizontal. The coefficient of friction between the body and the surface is 0.2. Find the magnitude of the normal force acting on the body.

12. (3 points) One mole of neon undergoes several processes. First, the gas is heated isobarically from 27°C to 47°C, then isochorically from 47°C to 57°C, and after that isobarically again from 57°C to 67°C.

a) By how many joules did the total internal energy of the neon increase across all three processes?

b) How much heat did the neon absorb during the isochoric heating?

c) How many joules of heat did the neon absorb during the first isobaric heating?

Take the universal gas constant to be $8.3\,\mathrm{J/(mol \cdot K)}$.

13. (2 points) An electric field moves a charge $q = 5\,\mathrm{C}$ in a DC circuit conductor, doing work $A = 30\,\mathrm{J}$. The resistance of this conductor is $R = 3\,\Omega$. How much heat will be released in the conductor if the same current flows for a time $t = 4\,\mathrm{s}$?

14. (3 points) A beam of light consisting of photons with momentum $p = 6.63 \cdot 10^{-27}\,\mathrm{kg \cdot m/s}$ is incident normally on a diffraction grating with grating spacing $d = 3\,\mu\mathrm{m}$. At what angle φ to the direction of the incident beam is the first order diffraction maximum observed? Note: You may express your answer as an inverse sine function, for example arcsin(...), without calculating its numerical value.

Physics

Variant 6

Part 1

Physics. Questions 1–10

Write your answer on Answer Sheet No. 1 to the right of the corresponding question number. Where applicable, include the units of measurement. If you need to correct an answer, cross out the incorrect one, enter the question number in the table below, and write the correct answer in the field to the right.

1. While walking around Samarkand, Mark walked 5 km south, then 5 km west, and then another 7 km south. What distance did Mark move from the starting point?

.... ***Answer:*** 13 km.

SOLUTION / PROOF :

Starting point: $(0, 0)$. After 5 km south: $(0, -5)$. After 5 km west: $(-5, -5)$. After another 7 km south: $(-5, -12)$. The distance from the start is $\sqrt{5^2 + 12^2} = \sqrt{25 + 144} = \sqrt{169} = 13$ km.

2. The Venus spacecraft with a mass of 220 kg descends at a constant speed in the atmosphere of Venus. The gravitational acceleration on Venus is 8.9 m/s^2. Find the air resistance force acting on the spacecraft.

.... ***Answer:*** 1958 N.

SOLUTION / PROOF :

During the uniform descent of the spacecraft, the gravitational force is balanced by the air resistance force: $F_{\text{resistance}} = mg$. Substituting the numerical values from the problem, $F_{\text{resistance}} = 220 \cdot 8.9 = 1958$ N.

3. During the laboratory experiment, the pressure of xenon dropped two times, while the concentration of gas molecules dropped 4 times. By how many times did the absolute temperature of xenon increase as a result?

.... ***Answer:*** 2.

SOLUTION / PROOF :

According to the basic equation of the kinetic theory of gases, $P = nkT$. Therefore, the absolute temperature can be expressed as $T = \frac{P}{nk}$. Let the initial pressure be P and the initial concentration be n. The new pressure is $P/2$, and the new concentration is $n/4$. Then $T_{\text{new}} = \frac{P/2}{(n/4)k} = \frac{4}{2} \cdot \frac{P}{nk} = 2T$. As a result, the absolute temperature increased 2 times.

4. 63 calories of heat heated 0.6 g of water from zero degrees Celsius to the boiling point. Use these data to calculate how many joules are in 1 calorie. The specific heat capacity of water is 4200 J/(kg · °C).

.... ***Answer:*** 4 J.

SOLUTION / PROOF :

The formula for the heat required to heat water is $Q = cm\Delta t$. According to the problem, the boiling point is 100°C, so the temperature change is $\Delta t = 100 - 0 = 100$°C. The mass of water in kilograms is $m = 0.6$ g $= 0.0006$ kg. The required heat in joules is $Q_{\text{joules}} = 4200 \cdot 0.0006 \cdot 100 = 252$ J. According to the condition, this heat is equal to 63 calories: 63 cal = 252 J. Therefore 1 cal = 252/63 = 4 J.

5. A point charge $q = +12$ nC is placed in a uniform horizontal electric field $E = 40$ kV/m. Find the magnitude of the total electric field at a point $h = 6.0$ cm directly above the charge.

.... ***Answer:*** $E \simeq 5.0 \times 10^4$ N/C.

SOLUTION / PROOF :

The total electric field is the vector sum of the uniform external field and the field created by the point charge. The external field is horizontal:

$$\vec{E}_0 = E_0 \hat{x}.$$

At the point directly above a positive charge, the field of the charge is directed vertically upward:

$$\vec{E}_q = E_q \hat{y}.$$

Its magnitude is found from Coulomb's law:

$$E_q = k\frac{|q|}{h^2}.$$

Substituting the values,

$$E_q = 9.0 \times 10^9 \frac{12 \times 10^{-9}}{(6.0 \times 10^{-2})^2} = 3.0 \times 10^4 \text{ N/C}.$$

Therefore the total field has perpendicular components

$$E_x = 4.0 \times 10^4 \text{ N/C}, \qquad E_y = 3.0 \times 10^4 \text{ N/C}.$$

The magnitude is

$$E = \sqrt{E_x^2 + E_y^2} = \sqrt{(4.0 \times 10^4)^2 + (3.0 \times 10^4)^2} = 5.0 \times 10^4 \text{ N/C}.$$

6. The voltage across a lamp depends on the current through it as $V = \alpha I^2$, where $\alpha = 2.0$ V/A^2. Find the power dissipated by the lamp for $I = 3.0$ A.

.... ***Answer:*** $P = 54$ W.

SOLUTION / PROOF :

The power dissipated by an electrical element is

$$P = IV.$$

The voltage is not given directly, but it is related to the current by

$$V = \alpha I^2.$$

Therefore

$$P = I(\alpha I^2) = \alpha I^3.$$

Substituting the values, we obtain

$$P = 2.0 \cdot (3.0)^3 = 54 \text{ W}.$$

7. A simple pendulum oscillates with a period of 2 s. A small adhesive weight of the same mass is carefully stuck to the bottom of its bob in such a way that the oscillations are not disturbed. Find the new frequency of the pendulum.

.... ***Answer:*** 500 mHz.

SOLUTION / PROOF :

The formula for the period of oscillation of a simple pendulum is $T = 2\pi\sqrt{l/g}$. Hence, the frequency is $f = 1/T$. The frequency of oscillation of a simple pendulum depends only on the acceleration due to gravity g and the length of the string l. The mass of the load is not included in the formula, so adding a sticky load of the same mass does not change the frequency. The new frequency remains $f = 1/2 = 0.5$ Hz. Converting to millihertz: 0.5 Hz = 0.5 · 1000 = 500 mHz.

8. Sebastian measured the sine of the critical angle for total internal reflection at the diamond–air interface and got 0.4. Use these data to find the refractive index of this diamond. Take the refractive index of air to be 1. Give your answer as a decimal fraction.

.... ***Answer:*** 2.5.

SOLUTION / PROOF :

The angle of incidence α of a light beam is measured from the normal to the interface between the media. During total internal reflection at the diamond–air interface, the angle of refraction is 90°. According to Snell's law, $n_1 \sin(\alpha_{\text{crit}}) = n_2 \sin(90°)$. Substituting the values given in the problem, with $n_2 = 1$ for air, $n_{\text{diamond}} \cdot 0.4 = 1 \cdot 1$. Therefore $n_{\text{diamond}} = 1/0.4 = 2.5$.

9. The transition from $n = 4$ to $n = 2$ corresponds to an energy of 2,07 eV. Determine the frequency of this photon.

.... ***Answer:*** 5.0×10^{14} Hz.

SOLUTION / PROOF :

Using the relation

$$E = h\nu,$$

where

$$h = 4.14 \times 10^{-15} \text{ eV} \cdot \text{s},$$

the frequency is

$$\nu = \frac{E}{h} = \frac{2.07}{4.14 \times 10^{-15}} \approx 0.5 \times 10^{15} = 5.0 \times 10^{14} \text{ Hz}.$$

10. A radioactive nucleus undergoes α-decay. How do its charge number and mass number change?
Record two digits in the answer sheet: first for charge, second for mass number.
Use: 1 = *increases*, 2 = *decreases*, 3 = *stays the same.*

.... ***Answer:*** *22*

SOLUTION / PROOF :

In α-decay, the nucleus emits an alpha particle, which consists of 2 protons and 2 neutrons. The number of neutrons decreases by 2, so this corresponds to digit 2. The nuclear charge, or number of protons, also decreases by 2, so this corresponds to digit 2. Therefore the answer is 22.

Physics. Questions 11–14

Use Answer Sheets No. 2 to write your solutions and answers to questions 11–14. Write your solution as completely and in as much detail as possible. Remember that even if you are unable to solve the problem completely, you may still receive some points for significant progress according to the marking criteria.

11. (2 points) A 1 kg body moves along a horizontal surface under the action of a 10 N force. This force is directed downward at an angle of 30° to the horizontal. The coefficient of friction between the body and the surface is 0.2. Find the magnitude of the normal force acting on the body.

.... ***Answer:*** 15 N.

SOLUTION / PROOF :

Let us analyze the forces acting on the body: the gravitational force mg is directed vertically downward, the normal force N is directed vertically upward, the external force F acts at an angle $\alpha = 30°$ downward to the horizontal, and the friction force acts opposite to the direction of motion. Newton's second law in projection onto the vertical axis gives

$$N - F\sin\alpha - mg = 0 \quad \Rightarrow \quad N = mg + F\sin\alpha.$$

Substituting the numerical values from the problem,

$$N = 1 \cdot 10 + 10 \cdot \sin(30°) = 10 + 10 \cdot 0.5 = 15 \text{ N}.$$

Marking Criteria: 2 points – the detailed solution is completely correct, and the right answer is obtained. 1 point – the applicant correctly projected the forces onto the vertical axis to find $N = mg + F\sin\alpha$, but further calculation is absent or incorrect. 0 points – the applicant incorrectly assumed that the normal force equals the gravitational force $N = mg$, or the solution does not meet the criteria, or the physical laws used are incorrect.

12. (3 points) One mole of neon undergoes several processes. First, the gas is heated isobarically from 27°C to 47°C, then isochorically from 47°C to 57°C, and after that isobarically again from 57°C to 67°C.

a) By how many joules did the total internal energy of the neon increase across all three processes?

b) How much heat did the neon absorb during the isochoric heating?

c) How many joules of heat did the neon absorb during the first isobaric heating?

Take the universal gas constant to be 8.3 J/(mol · K).

.... ***Answer:*** *1)* 498 J; *2)* 124.5 J; *3)* 415 J.

SOLUTION / PROOF :

a) Across all three processes, the total temperature change is $\Delta t = 67 - 27 = 40$°C. The internal energy of monatomic neon depends only on the initial and final temperatures:

$$\Delta U = 1.5 \cdot \nu R\Delta t = 1.5 \cdot 1 \cdot 8.3 \cdot 40 = 498 \text{ J}.$$

b) During isochoric heating, the gas performs no work; all heat goes into changing the internal energy. The temperature change in this step is $\Delta t = 57 - 47 = 10$°C. Thus

$$Q_{\text{isochoric}} = 1.5 \cdot \nu R\Delta t = 1.5 \cdot 1 \cdot 8.3 \cdot 10 = 124.5 \text{ J}.$$

c) The amount of heat during isobaric heating of a monatomic gas is $Q_{\text{isobaric}} = 2.5 \cdot \nu R\Delta t$. The temperature change in the first isobaric step is $\Delta t = 47 - 27 = 20$°C. Hence

$$Q_{\text{isobaric}} = 2.5 \cdot 1 \cdot 8.3 \cdot 20 = 415 \text{ J}.$$

Marking Criteria: 3 points – steps 1, 2, and 3 are solved correctly. 2 points – steps 1, 2, and 3 are solved correctly in general algebraic form, but there are calculation errors, or any 2 out of 3 steps are solved correctly. 1 point – any 1 out of 3 steps is solved correctly, or the fundamental formulas for thermodynamic processes are written correctly, but the subsequent solution is missing or incorrect. 0 points – the solution does not meet the criteria, or the physical laws used are incorrect.

13. (2 points) An electric field moves a charge $q = 5$ C in a DC circuit conductor, doing work $A = 30$ J. The resistance of this conductor is $R = 3\,\Omega$. How much heat will be released in the conductor if the same current flows for a time $t = 4$ s?

.... ***Answer:*** 48 J.

SOLUTION / PROOF :

From the definition of potential difference, $\Delta\varphi = \frac{A}{q} = \frac{30}{5} = 6$ V. By Ohm's law for a circuit section, the current is $I = \frac{\Delta\varphi}{R} = \frac{6}{3} = 2$ A. Now find the amount of heat for the given time interval $t = 4$ s using the Joule–Lenz law: $Q = I^2Rt = 2^2 \cdot 3 \cdot 4 = 4 \cdot 3 \cdot 4 = 48$ J.

14. (3 points) A beam of light consisting of photons with momentum $p = 6.63 \cdot 10^{-27}$ kg · m/s is incident normally on a diffraction grating with grating spacing $d = 3\,\mu$m. At what angle φ to the direction of the incident beam is the first order diffraction maximum observed? Note: You may express your answer as an inverse sine function, for example arcsin(...), without calculating its numerical value.

.... ***Answer:*** $\varphi = \arcsin\left(\frac{1}{30}\right)$.

SOLUTION / PROOF :

For normal incidence, the diffraction grating equation is

$$d\sin\varphi = m\lambda.$$

The photon momentum–wavelength relation is

$$p = \frac{h}{\lambda} \quad \Rightarrow \quad \lambda = \frac{h}{p}.$$

Substituting λ into the grating equation gives

$$d\sin\varphi = m \cdot \frac{h}{p}, \qquad \sin\varphi = \frac{mh}{dp}.$$

Substitution of numerical values gives

$$\sin\varphi = \frac{1 \cdot 6.63 \cdot 10^{-34}}{3 \cdot 10^{-6} \cdot 6.63 \cdot 10^{-27}} = \frac{1}{30}.$$

Therefore $\varphi = \arcsin\left(\frac{1}{30}\right)$.