TASHKENT UNIVERSITY OF TECHNOLOGY

Physics

Variant 1

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. A car starts moving with a constant acceleration of $3\,\mathrm{m/s^2}$. What speed will the car reach after 3 s of motion?

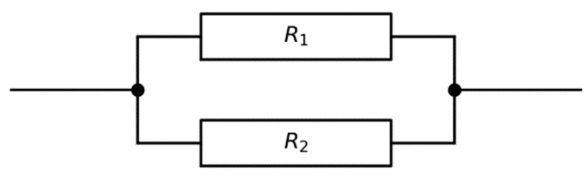
2. What mass should be suspended from a spring with a spring constant of $50\,\mathrm{N/m}$ so that it stretches by 2 cm?

3. A cylinder contains hydrogen at a temperature of 300 K. The cylinder can safely withstand a pressure that is 1.8 times the current pressure. To what maximum temperature can the cylinder be safely heated?

4. A heat engine operates according to the Carnot cycle. The temperature of its hot reservoir is 27°C, and the temperature of its cold reservoir is 9°C. Find the efficiency of the engine.

5. A point charge $q = 2 \cdot 10^{-9}\,\mathrm{C}$ is located in a vacuum. What is the electric potential at a point 3 m away from the charge?

6. In a DC circuit, two resistors are connected in parallel. The resistance of the first resistor is $R_1 = 30\,\Omega$, and the resistance of the second resistor is $R_2 = 60\,\Omega$. Find the total resistance of this part of the circuit.



7. The tables below show the displacement x as a function of time t for two simple pendulums, A and B.

Pendulum A

t, s	0	0.2	0.4	0.6	0.8	1.0
x, cm	0	3	0	−3	0	3

Pendulum B

t, s	0	0.2	0.4	0.6	0.8	1.0
x, cm	3	0	−3	0	3	0

Using these data, determine the phase difference between the oscillations of the two pendulums.

8. During an optics experiment, a student placed an object 30 cm in front of a thin converging lens. A sharp image of the object was obtained on a screen located 15 cm behind the lens. Determine the focal length of the lens.

9. A hydrogen atom is excited to the $n = 4$ energy level. Determine the total number of different spectral lines that can be emitted.

10. A beam of photons with an energy of 16 eV ejects photoelectrons from a metal. The maximum kinetic energy of the emitted photoelectrons is equal to one-third of the work function of the metal. Determine the maximum kinetic energy of the emitted photoelectrons.

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 200 g block is pulled horizontally across a horizontal table using a spring balance with a gradually increasing force. When the spring balance reads 1.5 N, the block just begins to move. Determine the coefficient of friction between the block and the table when the spring balance reads 3 N.

12. (3 points) A crack has formed in the hull of a spacecraft. The onboard sensors indicate that the air pressure inside the spacecraft has decreased by 5%. Assume that the air behaves as an ideal gas. The air temperature and the volume of the spacecraft remain constant. Initially, the spacecraft contained 2 kmol of air.
Determine:
(a) By what percentage has the amount of substance of the air decreased?
(b) What is the mass of air remaining inside the spacecraft?
(c) Astronaut Henri Bocanhel reports that the sensors were operating normally 10 min ago. Determine the minimum possible average mass loss rate of the escaping air.

13. (2 points) An electric field in a DC circuit performs 200 J of work while transferring a charge through a heating element during 2 s. Determine the electric power dissipated by the heating element.

14. (3 points) A plane monochromatic wave is incident normally on a diffraction grating with a grating spacing of $d = 0.004$ mm. A total of 19 principal diffraction maxima are observed. Determine the wavelength of the incident light.

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Part 1

Physics. Questions 1–10

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1. A car starts moving with a constant acceleration of $3\,\mathrm{m/s^2}$. What speed will the car reach after 3 s of motion?

.... ***Answer:*** 9 m/s

SOLUTION / PROOF :

The speed of a body moving with constant acceleration is given by

$$v = v_0 + at.$$

Since the car starts from rest,

$$v_0 = 0.$$

Substitute the given values:

$$v = 0 + 3 \cdot 3 = 9\,\mathrm{m/s}.$$

$$v = 9\ \mathrm{m/s}$$

2. What mass should be suspended from a spring with a spring constant of $50\,\mathrm{N/m}$ so that it stretches by 2 cm?

.... ***Answer:*** 0.1 kg

SOLUTION / PROOF :

At equilibrium, the spring force is equal to the weight of the mass:

$$kx = mg.$$

Convert the extension to metres:

$$x = 2\,\mathrm{cm} = 0.02\,\mathrm{m}.$$

Express the mass:

$$m = \frac{kx}{g}.$$

Substitute the given values:

$$m = \frac{50 \cdot 0.02}{10} = \frac{1}{10} = 0.1\,\mathrm{kg}.$$

$$m = 0.1\ \mathrm{kg}$$

3. A cylinder contains hydrogen at a temperature of 300 K. The cylinder can safely withstand a pressure that is 1.8 times the current pressure. To what maximum temperature can the cylinder be safely heated?

.... ***Answer:*** 540 K *or* 267°C

SOLUTION / PROOF :

Since the volume of the cylinder is constant,

$$\frac{P}{T} = \text{const}.$$

Therefore,

$$\frac{P_2}{P_1} = \frac{T_2}{T_1}.$$

The maximum allowable pressure is

$$P_2 = 1.8P_1.$$

Hence,

$$T_2 = 1.8T_1.$$

Substitute the given values:

$$T_2 = 1.8 \cdot 300 = 540\,\mathrm{K}.$$

Convert the result to degrees Celsius:

$$t_2 = T_2 - 273 = 540 - 273 = 267^\circ\mathrm{C}.$$

$$T_2 = 540\ \mathrm{K} = 267^\circ\mathrm{C}$$

4. A heat engine operates according to the Carnot cycle. The temperature of its hot reservoir is 27°C, and the temperature of its cold reservoir is 9°C. Find the efficiency of the engine.

.... ***Answer:*** 6%

SOLUTION / PROOF :

The efficiency of a Carnot engine is

$$\eta = 1 - \frac{T_c}{T_h},$$

where the temperatures are measured in kelvins.
Convert the temperatures:

$$T_h = 27 + 273 = 300\,\mathrm{K},$$

$$T_c = 9 + 273 = 282\,\mathrm{K}.$$

Substitute the given values:

$$\eta = 1 - \frac{282}{300} = 0.06.$$

Express the result as a percentage:

$$\eta = 6\%.$$

$$\eta = 6\%$$

5. A point charge $q = 2 \cdot 10^{-9}\,\mathrm{C}$ is located in a vacuum. What is the electric potential at a point 3 m away from the charge?

.... ***Answer:*** 6 V

SOLUTION / PROOF :

The electric potential of a point charge is given by

$$\varphi = k \cdot \frac{q}{r},$$

where

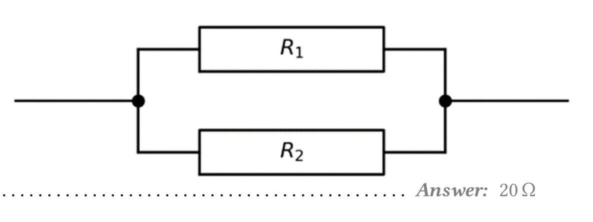
$$k = 9 \cdot 10^9\,\mathrm{N \cdot m^2/C^2}.$$

Substitute the given values:

$$\varphi = 9 \cdot 10^9 \cdot \frac{2 \cdot 10^{-9}}{3} = \frac{18}{3} = 6\,\mathrm{V}.$$

$$\varphi = 6\ \mathrm{V}$$

6. In a DC circuit, two resistors are connected in parallel. The resistance of the first resistor is $R_1 = 30\,\Omega$, and the resistance of the second resistor is $R_2 = 60\,\Omega$. Find the total resistance of this part of the circuit.



.... ***Answer:*** 20 Ω

SOLUTION / PROOF :

For two resistors connected in parallel, the total resistance is given by

$$R_{\text{total}} = \frac{R_1 R_2}{R_1 + R_2}.$$

Substitute the given values:

$$R_{\text{total}} = \frac{30 \cdot 60}{30 + 60} = \frac{1800}{90} = 20\,\Omega.$$

$$R_{\text{total}} = 20\ \Omega$$

7. The tables below show the displacement x as a function of time t for two simple pendulums, A and B.

Pendulum A

t, s	0	0.2	0.4	0.6	0.8	1.0
x, cm	0	3	0	−3	0	3

Pendulum B

t, s	0	0.2	0.4	0.6	0.8	1.0
x, cm	3	0	−3	0	3	0

Using these data, determine the phase difference between the oscillations of the two pendulums.

.... ***Answer:*** $\frac{\pi}{2}$

SOLUTION / PROOF :

From the tables, the oscillations have the same period:

$$T = 0.8\,\mathrm{s}.$$

Pendulum B reaches each displacement value 0.2 s earlier than pendulum A.
Therefore, the time shift is

$$\Delta t = 0.2\,\mathrm{s} = \frac{T}{4}.$$

The phase difference is

$$\Delta\varphi = 2\pi\frac{\Delta t}{T} = 2\pi \cdot \frac{1}{4} = \frac{\pi}{2}.$$

$$\Delta\varphi = \frac{\pi}{2}$$

8. During an optics experiment, a student placed an object 30 cm in front of a thin converging lens. A sharp image of the object was obtained on a screen located 15 cm behind the lens. Determine the focal length of the lens.

.... ***Answer:*** 10 cm

SOLUTION / PROOF :

For a thin lens,

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

where

$$a = 30\,\mathrm{cm}, \qquad b = 15\,\mathrm{cm}.$$

Substitute the given values:

$$\frac{1}{f} = \frac{1}{30} + \frac{1}{15} = \frac{1}{30} + \frac{2}{30} = \frac{3}{30} = \frac{1}{10}.$$

Therefore,

$$f = 10\,\mathrm{cm}.$$

$$f = 10\ \mathrm{cm}$$

9. A hydrogen atom is excited to the $n = 4$ energy level. Determine the total number of different spectral lines that can be emitted.

.... ***Answer:*** 6

SOLUTION / PROOF :

The total number of possible spectral lines emitted during transitions between energy levels is

$$N = \frac{n(n-1)}{2},$$

where n is the highest excited energy level.
For

$$n = 4,$$

we obtain

$$N = \frac{4(4-1)}{2} = \frac{4 \cdot 3}{2} = 6.$$

$$N = 6$$

10. A beam of photons with an energy of 16 eV ejects photoelectrons from a metal. The maximum kinetic energy of the emitted photoelectrons is equal to one-third of the work function of the metal. Determine the maximum kinetic energy of the emitted photoelectrons.

.... ***Answer:*** 4 eV

SOLUTION / PROOF :

According to Einstein's photoelectric equation,

$$E_\gamma = A + K_{\max},$$

where A is the work function and $K_{\max}$ is the maximum kinetic energy of the photoelectrons.
Since

$$K_{\max} = \frac{A}{3},$$

we have

$$16 = A + \frac{A}{3} = \frac{4A}{3}.$$

Therefore,

$$A = 12\,\mathrm{eV},$$

and

$$K_{\max} = \frac{12}{3} = 4\,\mathrm{eV}.$$

$$K_{\max} = 4\ \mathrm{eV}$$

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11. (2 points) A 200 g block is pulled horizontally across a horizontal table using a spring balance with a gradually increasing force. When the spring balance reads 1.5 N, the block just begins to move. Determine the coefficient of friction between the block and the table when the spring balance reads 3 N.

.... ***Answer:*** 0.75

SOLUTION / PROOF :

The coefficient of friction is

$$\mu = \frac{F_{\text{fr}}}{N}.$$

At the moment the block starts to move, the pulling force equals the maximum static friction force:

$$F_{\text{fr}} = 1.5\,\mathrm{N}.$$

The normal force is

$$N = mg = 0.2 \cdot 10 = 2\,\mathrm{N}.$$

Therefore,

$$\mu = \frac{1.5}{2} = 0.75.$$

The coefficient of friction is a property of the contacting surfaces and does not depend on the pulling force. Therefore, when the spring balance reads 3 N, the coefficient of friction remains

$$\mu = 0.75.$$

$$\mu = 0.75$$

12. (3 points) A crack has formed in the hull of a spacecraft. The onboard sensors indicate that the air pressure inside the spacecraft has decreased by 5%. Assume that the air behaves as an ideal gas. The air temperature and the volume of the spacecraft remain constant. Initially, the spacecraft contained 2 kmol of air.
Determine:
(a) By what percentage has the amount of substance of the air decreased?
(b) What is the mass of air remaining inside the spacecraft?
(c) Astronaut Henri Bocanhel reports that the sensors were operating normally 10 min ago. Determine the minimum possible average mass loss rate of the escaping air.

.... ***Answer:*** 5%; 55.1 kg; ≥ 4.8 g/s

SOLUTION / PROOF :

For an ideal gas,

$$pV = nRT.$$

Since the volume and temperature remain constant,

$$p \propto n.$$

Therefore, a 5% decrease in pressure corresponds to a 5% decrease in the amount of substance.
Initially,

$$n_0 = 2\,\mathrm{kmol} = 2000\,\mathrm{mol}.$$

The remaining amount of substance is

$$n = 0.95n_0 = 1900\,\mathrm{mol}.$$

The remaining mass of air is

$$m = nM = 1900 \cdot 0.029 = 55.1\,\mathrm{kg}.$$

The leaked mass is

$$\Delta m = 0.05 \cdot 2000 \cdot 0.029 = 2.9\,\mathrm{kg}.$$

Since the sensors were operating normally 10 min ago, the leak has existed for no more than

$$\Delta t \le 600\,\mathrm{s}.$$

Hence the average mass loss rate satisfies

$$\dot m = \frac{\Delta m}{\Delta t} \ge \frac{2.9}{600} \approx 4.8 \times 10^{-3}\,\mathrm{kg/s} = 4.8\,\mathrm{g/s}.$$

$$5\%, \qquad 55.1\ \mathrm{kg}, \qquad \dot m \ge 4.8\ \mathrm{g/s}$$

13. (2 points) An electric field in a DC circuit performs 200 J of work while transferring a charge through a heating element during 2 s. Determine the electric power dissipated by the heating element.

.... ***Answer:*** 100 W

SOLUTION / PROOF :

Electric power is equal to the work done per unit time:

$$P = \frac{A}{t} = \frac{200}{2} = 100\,\mathrm{W}.$$

$$P = 100\ \mathrm{W}$$

14. (3 points) A plane monochromatic wave is incident normally on a diffraction grating with a grating spacing of $d = 0.004\,\mathrm{mm}$. A total of 19 principal diffraction maxima are observed. Determine the wavelength of the incident light.

.... ***Answer:*** 440 nm

SOLUTION / PROOF :

The greatest diffraction order is

$$k_{\max} = \frac{19 - 1}{2} = 9.$$

Since

$$k_{\max} = \frac{d}{\lambda},$$

we obtain

$$\lambda = \frac{d}{9} = \frac{4000}{9} \approx 440\,\mathrm{nm}.$$

$$\lambda = 440\ \mathrm{nm}$$