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PROBLEMS IN GENERAL PHYSICS

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TO THE READER

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На английском языке

PREFACE

This collection of problems is based on the International System of Units preferred today in all the fields of science, engineering and economy.

Other units can be converted to SI units with the aid of the relevant tables given in this book.

Each section is preceded by a brief introduction describing the fundamental laws and formulas which are used to solve the problems. The solutions to the problems and the reference data are appended at the end of the book.

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ANSWERS AND SOLUTIONS

INTRODUCTION

1. International System of Units (SI)

Various physical quantities are interrelated by equations which express the relation between them. For example, the acceleration a imparted to a body with the mass m is related to the force F acting upon this body by the equation

$$F = kma \tag{1}$$

where k is a factor depending on the units in which F, m and a are measured. If the units of mass and acceleration are known, the unit of force can be so selected that the factor k in equation (1) is equal to unity, and thus

$$F = ma$$

With this aim, the unit of force should be the force which imparts a unit of acceleration to a unit of mass.

By treating any newly introduced quantity in the same manner, its unit of measurement can be found from the formula which determines this quantity; thus a system of derived units can be obtained.

Various systems differ from each other by the units taken as the basic ones.

This book is based on the International System of Units (SI) adopted by the Éleventh General Conference on Weights and Measures in 1960. The USSR State Standard GOST 9867-61 defines the SI system as the one preferable in all the fields of science, engineering and the national economy, and also in schools and colleges of the USSR.

The International System of Units (SI) is divided into several independent systems for various fields of measurement, as follows:

1. System of mechanical units (GOST 7664-61).
2. System of thermal units (GOST 8550-61).
3. System of electrical and magnetic units (GOST 8033-56).
4. System of acoustic units (GOST 8849-58).
5. System of light units (GOST 7932-56).
6. System of radioactivity and ionizing radiation units (GOST 8848-63).

The basic SI mechanical units are the metre (m), kilogramme-mass (kg) and second (s). Added to these for various fields of measurement are the following basic units: the degree Kelvin for thermal measurements, the ampere for electrical measurements and the candela for luminous intensity.

The SI system also includes two supplementary units—for a plane angle and a solid angle.

The basic and supplementary SI units are given in Table 1.

TABLE 1

Quantity	Unit	Symbol
	Basic Units	
Length	metre	m
Mass	kilogramme	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	degree Kelvin	°K
Luminous intensity	candela	cd
	Supplementary Units	
Plane angle	radian	rad
Solid angle	steradian	sr

Table 2 gives the prefixes used to form multiples and fractions of SI units.

TABLE 2

Prefix	Numerical value	Symbol	Prefix	Numerical value	Symbol
Atto	10^{-18}	a	Deci	10^{-1}	d
Femto	10^{-15}	f	Deca	10^{1}	da
Pico	10^{-12}	p	Hecto	10^{2}	h
Nano	10^{-9}	n	Kilo	10^{3}	k
Micro	10^{-6}	μ	Mega	10^{6}	M
Milli	10^{-3}	m	Giga	10^{9}	G
Centi	10^{-2}	c	Tera	10^{12}	T

These prefixes in Table 2 may be attached only to simple quantities (metre, gramme, etc.) and never to such as "kilogramme", which already contains the prefix "kilo". For the same reason, the unit of mass $m=10^9$ kg $=10^{12}$ g, for example, should be called "teragramme" (Tg).

The term "megaton" sometimes applied to this mass is wrong. The unit of length $l=10^{-6}$ m is generally called a "micron", but the more proper name would be "micrometre" (μm).

The derived SI units are formed from the basic ones as described above. The relationship between the derived and basic units can be found from dimension formulas.

If the basic quantities are designated by l for length, m for mass, t for time, I for electric current, θ for temperature and J for luminous intensity, the dimension formula of a certain quantity x may be written in SI units as follows:

$$[x] = l^{\alpha} m^{\beta} t^{\gamma} I^{\delta} \theta^{\rho} J^{\mu}$$

To find the dimension of x, we must determine the exponents α, β, γ, δ, ρ and μ. These exponents may be positive or negative, integers or fractions.

Example 1. Find the dimension of work. Proceeding from the relation $W=Fl$, we obtain $[W]=l^2mt^{-2}$.

Example 2. Find the dimension of specific heat. Since $c=\frac{Q}{m\Delta\theta}$ and $[Q]=[W]$, we get $[c]=l^2t^{-2}\theta^{-1}$.

If the dimension of a physical quantity is known in the SI system, it is easy to find the dimension of its unit in this system. Thus, the unit of work obviously has the dimension m^2kgs^{-2} and the unit of specific heat—$m^2s^{-2}deg^{-1}$, etc.

Tables of derived SI units are given in the respective sections of the book: mechanical units in Chapter 1, thermal units in Chapter 2, electrical and magnetic units in Chapter 3, etc. The same chapters also contain tables which establish the relationship between the SI and other units, including non-system ones.

2. Methods of Solving Problems

When solving a problem, first of all establish the physical laws which it is based on. Then use the formulas expressing these laws to solve the problem in symbols, and finally substitute the numerical data in one system of units. Besides the International System of Units, other systems and non-system units are widely used in practice and literature. For this reason the numerical data are not always given in SI units. The relationships between the SI units, units of other systems and non-system units are given in tables at the beginning of each chapter. To solve a problem in SI units, all the initial data or data taken from reference tables should be converted into SI units. The answer, naturally, will also be in these units.

Sometimes it is not necessary to express all the data in one system. For example, if a quantity is a factor of both the numerator and the denominator, this quantity may obviously be expressed in any units provided they are the same (see Example 2 on p. 17).

When a numerical answer is obtained, pay attention to the accuracy of the final result, which should never exceed the accuracy of the initial data. Most of the problems may be solved with slide-rule accuracy. In some cases tables of four-place logarithms should be used.

As soon as the numerical data are substituted for the symbols, write the dimension of the answer.

If a graph or a diagram is required for solution, select the proper scale and origin of the coordinates, and mark the scale on the graph. The graphs in the answers to some problems are given without a scale, i. e., they show only the qualitative nature of the relationship being sought.

PROBLEMS

Chapter 1

PHYSICAL FUNDAMENTALS OF MECHANICS

MECHANICAL UNITS

The International System of Units incorporates the MKS system intended for measuring mechanical quantities (GOST 7664-61). The basic units in the MKS system are the metre (m), kilogramme (kg) and second (s).

As indicated above, the derived units of this system are formed from the basic units using the relationship between the relevant physical quantities. For example, the unit of velocity can be determined from the relation

$$v = \frac{\Delta l}{\Delta t}$$

Since the unit of length is the metre and that of time the second, the unit of velocity in the MKS system will be 1 m/s. Obviously, the unit of acceleration is 1 m/s².

Let us establish the unit of force. According to Newton's second law

$$F = ma$$

The unit of mass is 1 kg and the unit of acceleration 1 m/s². Therefore, the unit of force in the MKS system should be the force which imparts an acceleration of 1 m/s² to a body with a mass of 1 kg. This unit of force is known as the newton (N):

$$1\ \text{N} = 1\ \text{kg} \cdot 1\ \text{m/s}^2$$

Let us now discuss the relation between the weight and mass of a body. The weight G of a body is the force with which this body is attracted by the Earth, i.e., the force which imparts an acceleration of $g = 9.81$ m/s² to the body. Thus,

$$G = mg$$

As any other force in the MKS system, the weight of a body must be measured in newtons. Sometimes it is measured in kilogrammes

But it should always be borne in mind that the unit of weight (kilogramme) is not a unit of the MKS system. To prevent confusion, different symbols will be used for these two utterly different physical quantities: a kilogramme of mass will be denoted kg, and one of weight (force)—kgf. Let us find the relation between a kilogramme of weight and a newton. A weight of 1 kgf is defined as the weight of a body whose mass is equal to 1 kg, i.e.,

$$1\ \text{kgf}=1\ \text{kg}\cdot 9.81\ \text{m/s}^2$$

On the other hand

$$1\ \text{N}=1\ \text{kg}\cdot 1\ \text{m/s}^2$$

Therefore

$$1\ \text{kgf}=9.81\ \text{N}$$

The definition of a kilogramme of weight shows that the numerical value of the weight of a body expressed in kgf is equal to the mass of this body in kg. For example, if the mass of a body is 2 kg, its weight is 2 kgf. The weight of a body in kilogrammes must be converted into newtons.

Example. The mass of a body is 4 kg. Find the weight of the body in kgf and in newtons.

Answer: $G=4$ kgf (not in the MKS system) and $G=4\times 9.81$ N (in the MKS system).

The unit of work is determined from the relation

$$W=Fl$$

The unit of work is obviously the work performed by a force of 1 N over a distance of 1 metre. This unit of work is known as the joule (J):

$$1\ \text{J}=1\ \text{N}\cdot 1\ \text{m}$$

Power is determined by the formula

$$P=\frac{W}{t}$$

Therefore the unit of power in the MKS system is the power of a mechanism which performs work of 1 J per second. This unit is known as the watt (W).

The same method can be used to determine the derived unit of any physical quantity in the MKS system.

Table 3 gives the basic and the most important derived units for measuring mechanical quantities in the MKS system according to GOST 7664-61.

Table 4 contains the relationships between certain mechanical SI units, and units of other systems and non-system units permitted by GOST 7664-61.

TABLE 3

Quantity and symbol	Formula	Unit	Symbol of unit	Dimension of quantity
		Basic units		
Length l	—	metre	m	l
Mass m	—	kilogramme	kg	m
Time t	—	second	s	t
		Derived units		
Area A	$A = l^2$	square metre	m^2	l^2
Volume V	$V = l^3$	cubic metre	m^3	l^3
Frequency ν	$\nu = \frac{1}{T}$	hertz	Hz	t^{-1}
Angular velocity ω	$\omega = \frac{\Delta\varphi}{\Delta t}$	radian per second	rad/s	t^{-1}
Angular acceleration α	$\alpha = \frac{\Delta\omega}{\Delta t}$	radian per second per second	rad/s^2	t^{-2}
Linear velocity v	$v = \frac{\Delta l}{\Delta t}$	metre per second	m/s	lt^{-1}
Linear acceleration a	$a = \frac{\Delta v}{\Delta t}$	metre per second per second	m/s^2	lt^{-2}
Density ρ	$\rho = \frac{m}{V}$	kilogramme per cubic metre	kg/m^3	$l^{-3}m$
Force F, weight G	$F = ma$	newton	N	lmt^{-2}
Specific weight γ	$\gamma = \frac{G}{V}$	newton per cubic metre	N/m^3	$l^{-2}mt^{-2}$
Pressure p	$p = \frac{F}{A}$	newton per square metre	N/m^2	$l^{-1}mt^{-2}$
Momentum $\overline{p}$	$\overline{p} = m\,\Delta v = F\,\Delta t$	kilogramme-metre per second	kg·m/s	lmt^{-1}
Moment of inertia I	$I = ml^2$	kilogramme-square metre	kg·m^2	l^2m
Work W and energy E	$W = Fl$	joule	J	l^2mt^{-2}
Power P	$P = \frac{\Delta W}{\Delta t}$	watt	W	l^2mt^{-3}
Dynamic viscosity η	$\eta = \frac{F}{A}\frac{\Delta l}{\Delta v}$	newton-second per square metre	N·s/m^2	$l^{-1}mt^{-1}$
Kinematic viscosity ν	$\nu = \frac{\eta}{\rho}$	square metre per second	m^2/s	l^2t^{-1}

TABLE 4

Quantity	Unit and its conversion factor to SI units
Length	1 centimetre (cm) $= 10^{-2}$ m 1 micrometre (micron); 1 micron (μ) $= 10^{-6}$ m 1 angström (Å) $= 10^{-10}$ m
Mass	1 gramme (g) $= 10^{-3}$ kg 1 ton (t) $= 10^3$ kg 1 centner (q) $= 10^2$ kg 1 atomic unit of mass (a.u.m.) $= 1.66 \times 10^{-27}$ kg
Plane angle	1 degree (°) $= \frac{\pi}{180}$ rad 1 minute (′) $= \frac{\pi}{108} \times 10^{-2}$ rad 1 second (″) $= \frac{\pi}{648} \times 10^{-3}$ rad 1 revolution (rev) $= 2\pi$ rad
Area	1 are (a) $= 100$ m^2 1 hectare (ha) $= 10^4$ m^2
Volume	1 litre (l) $= 1.000028 \times 10^{-3}$ m^3
Force	1 dyne (dyn) $= 10^{-5}$ N 1 kilogramme-force (kgf) $= 9.81$ N 1 ton-force (tonf) $= 9.81 \times 10^3$ N
Pressure	1 dyn/cm^2 $= 0.1$ N/m^2 1 kgf/m^2 $= 9.81$ N/m^2 1 millimetre of mercury column (mm Hg) $= 133.0$ N/m^2 1 millimetre of water column (mm H_2O) $= 9.81$ N/m^2 1 technical atmosphere (at) $= 1$ kgf/cm^2 $= 0.981 \times 10^5$ N/m^2 1 physical atmosphere (atm) $= 1.013 \times 10^5$ N/m^2 (this non-system unit is not listed in GOST 7664-61)
Work, energy, amount of heat	1 erg $= 10^{-7}$ J 1 kgf-m $= 9.81$ J 1 watt-hour (W-h) $= 3.6 \times 10^3$ J 1 electron-volt (eV) $= 1.6 \times 10^{-19}$ J 1 calorie (cal) $= 4.19$ J 1 kilocalorie (1 kcal) $= 4.19 \times 10^3$ J 1 physical litre-atmosphere (l·atm) $= 1.01 \times 10^2$ J 1 technical litre-atmosphere (l·at) $= 98.1$ J
Power	1 erg/s $= 10^{-7}$ W 1 kilogramme-force metre per second (kgf-m/s) $= 9.81$ W 1 horsepower (hp) $= 75$ kgf-m/s $= 736$ W
Dynamic viscosity	1 poise (P) $= 0.1$ N·s/m^2 $= 0.1$ kg/m·s
Kinematic viscosity	1 stokes (St) $= 10^{-4}$ m^2/s