32. Problems in Physics

The problems published in this collection were compiled by me for students of the Moscow Physical-Technical Institute, where I taught a course in general physics in 1947–1949. The collection also includes problems given at examinations for postgraduate studies at the Institute of Physical Problems at the USSR Academy of Sciences. The problems were selected and prepared for printing by I.Sh. Slobodetskii and L.G. Aslamazov, who recently graduated from the Physical-Technical Institute.

In compiling these problems I had a certain objective in mind, which explains their unconventional formulation. The following explanation will make their solution of greater interest to the reader.

Problem solving is of particular importance in the study of the exact sciences such as mathematics, mechanics, physics, etc. It enables the student to apply his own knowledge to the solution of practical questions. Moreover, for the teacher it represents an excellent means for finding out whether the student really understands the subject or whether his knowledge is a mere accumulation of facts learned by heart. Teaching by means of problem solving also helps in revealing and cultivating the creative scientific thinking of the young generation. The need for this was quite evident 25 years ago when the Physical-Technical Institute was founded as an institution of higher learning intended specifically for the selection and training of research workers. It is well known that fruitful scientific work requires not only knowledge and under standing but also a capacity for independent analytical and creative thinking. In effect, these problems were compiled as a useful means for the discovery, evaluation and cultivation of these qualities during the teaching process.

I strove to achieve this end by formulating the majority of questions in the following manner. A small problem is presented, and the student, using the known laws of physics, must analyse and describe quantitatively the natural phenomenon involved. These natural phenomena were selected in terms of their scientific or practical interest within the scope of the students' level of knowledge.

Most of the problems allow a number of approaches to their solution in order to reveal the student's individuality. One example is the problem of the trajectory of an airplane with a state of weightlessness in its cabin. Here the standard approach would be to write the equation of the plane's motion in the gravitational field of the Earth, taking the resultant of forces acting on a point inside the plane as equal to zero. There is, however, another, simpler solution. If the plane follows the trajectory of a freely flying body, which is close to a parabola in the Earth's field, then a body located inside the plane can be in a state of weightlessness. The curious student can pursue the matter further and find out what is required during the flight in order simultaneously to achieve a state of weightlessness at all points of the plane's cabin. Another question that can be considered is what navigational instruments are necessary for the pilot to fly the plane along the trajectory required for weightlessness. etc.

A characteristic feature of our problems is that they have no definite answer because the student is allowed to proceed further and further with the analysis of the problem posed, depend ing on his own abilities and inclinations.

The student's answers provide a clue to the trend and nature of his scientific thinking, which is of particular importance in the selection of postgraduate workers. The independent solution of such problems stimulates the capacity for scientific thinking and cultivates an attraction to scientific problems.

Most of the problems have another distinctive trait. They do not contain numerical values of physical constants or parameters, and the student has to choose them personally, Thus, in the problem of weightlessness in an airplane the student is asked to determine the duration of weightlessness, though it is mentioned that the airplane is of a modern type. Here the student has to pick out the airplane's ceiling and maximum speed for himself. We did so because few people in our country appear to care whether the future sceintist or engineer is taught to ima gine the actual magnitudes of such common physical values as velocity, current, voltage, strength, temperature, etc. in concrete terms.

In solving a scientific problem the research scientist always has to visualize clearly the magnitude and relative significance of the parameters used for describing the phenomenon examined. Thus he will be able to pick out the crucial parameters for the study of the given phenomenon. Hence the importance of teaching the young generation that the symbols which represent physical magnitudes in the formulae should always be visualized in terms of concrete quantitative values. In physics, contrary to mathematics, both the parameters and the variables in a mathematical equation necessarily represent concrete quantities. In our problems we therefore train the students to seek out the required magnitudes for themselves in the literature.

The students of the Physical-Technical Institute showed interest in these problems and frequently subjected them to collective discussion. In the examinations, the students were always given complete freedom to use literature for solving the problems. Usually a few (up to 5) problems were given per examination, so as to enable the students to choose 2 3 of them. Thus, the inclinations of a student could be gauged from his selection of problems. For post graduate examinations, new and more complex problems were prepared; in these cases, however, the student was allowed not only use of literature but also freedom to seek advice. Indeed, the scientist must cultivate the skill of using the advice of others, apart from learning the use of literature. In scientific work, discussions and consultations with colleagues and instructors are essential for success; this, however, requires a proper training from the very beginning of the studies.

We usually allowed about one hour for the solution of each problem. All problems have to be solved in writing, but the capabilities and character of the student become evident mostly in the course of a verbal discussion of the written text. The greater the talent of the young scientist, the

more than an hour.

Today there is no doubt as to the enormous importance of science for the development of the culture and economy of a modern state. The number of Sovient scientists and research workers is constantly rising, having already exceeded half a million. For this reason the training and education of young scientists is nothing less than a major, independent objective of the state.

Apart from the Moscow Physical-Technical Institute, there are a number of other institutions of higher education in the USSR intended specifically for the training of research cadres. Teaching at these institutions undoubtedly has specific traits of its own, as distinct from the universities which produce cadres for industry and the national economy. I believe that problems comparable to those complied by us can be used not only in the teaching of physics but also in other exact sciences such as mathematics, mechanics, chemistry, etc. The solution of problems comparable to those given here will therefore improve the training of future researchers.

1. Astronomical observations show that the planet Venus is entirely covered in cloud, so that the Venusians are unable to observe the heavenly bodes, Describe how they could accurately measure the length of their day.

2. The Tungus meteorite struck the earth at latitude 60°, and all its energy was converted into heat, so that it evaporated. Assuming that it weighed 10,000 tons and had a speed of 50 km/s, calculate the maximum effect that the impact can have had on the earth's axial rotation. Could such a change be detected by present-day clocks?

3. What should be the trajectory of a modern aircraft in order to simulate a state of weightlessness? For how long could such a condition be maintained?

4. Determine the limit of accuracy of time interval measurement with a cathode-ray oscillograph.

5. The ancients used a water-pump operating as follows. A tube bent into a helix rotates about a central axis at an angle α to the water surface. The lower end of the tube is in the water, The water is raised to a height h. Find the optimum value of α, the throughput of the pump, and its efficiency.

6. Neutrons pass readily through a lead block, but are stopped by the same volume of paraffin, water, or other compound containing hydrogen atoms. Why is this?

7. A parachutist, as he falls, pulls on the front shroud lines. In which direction will he then travel?

8. A car tyre bursts during a race, At what speed should the car travel so that the tyre does not deflate?

9 To protect passengers in car crashes, air bags can be used, which are rapidly filled with gas and absorb the impact. Assess the effectiveness of this technique. If a vehicle moving at 100 km/h crashes, and a person's head striking the bag is not injured, what must be the size of the bag and the gas pressure in it?

10. By what factor can the height of an acrobat's jump be increased by using a springboard once?

11. Explain why, for a bow of a given size, there is a certain size of arrow which yields the longest flight. Estimate this size for a bow of a given shape.

12. An acrobat of weight P stands on a ball of radius R and mass M. The ball is on a horizontal plane, and rolls without slipping on the plane. Analyse the way in which the acro bat should walk on the ball in order to make it roll, and how the coefficient of friction of his soles is related to the rolling acceleration.

13. What must be the speed of a tennis ball that can break glass?

14. A ball thrown on to a solid surface rebounds from it. Estimate the dependence of the height of rebound on the viscosity of the solid.

15. Estimate the duration of impact between a football and a wall.

16. A steel ball falls from a height $h = 10$ cm on an inclined plane (angle α 10°), rebounds elastically, falls again, and so on. Describe the motion, assuming that the plane is of unlimited length and that the impacts take place without loss.

17. Explain why a person can run on very thin ice but cannot stand on it without falling through.

18 Estimate the order of magnitude of the speed at which a person must run on water in order not to sink.

19. Why can the movement of a bicycle be controlled in 'no hands' riding?

20. A satellite passes over Novosibirsk at 02.30, and over Moscow at 06.00. Where will it be at 20.00 and at 21.45? (Moscow time is used).

21. A spaceship is travelling from the earth to Mars. Half of its surface is blackened and absorbs the sun's radiation completely: the other half is polished metal, and reflects the sun's radiation completely. Examine how radiation pressure will affect the translational and rotational motion of the craft. Make a quantitative estimate of the effect for a spherical craft of mass 5 tons and diameter 300 cm.

22. A container of water in which a water rat is swimming is in equilibrium on a balance. A string is lowered from a rod attached to the other side of the balance, so as to touch the water. The rat begins to climb up the string. Will equilibrium be maintained?.

23. A fly is sitting on the bottom of a beaker that is on a balance. The fly flies away. At what point in time will the balance first register the departure of the fly?

24. Determine the distortion of a liquid surface due to the gravitation of a sphere. Discuss the possibility of oberving this effect in order to measure the gravitational constant.

25. Determine the minimum size of an object distinguishable on a photograph taken from a satellite at a height of 300 km.

26. An astronaut in a state of weightlessness has to dig a well. How can he do this?

27. A rocket with mass M is motionless above the earth's surface. The speed of the gases leaving the rocket is u. Find the power of the rocket's engine.

28. What will be the trajectory of a bullet fired forwards/backwards/sideways from a satellite.

29. How can an astronaut return to his spacecraft if the rope joining him to it accidentally breaks.

30. How can the direction of flight of a satellite (weight 100 kg, orbit radius 400 km) be changed by 2°? Describe in principle the possible ways of performing this manoeuvre.

31. As the earth moves in its elliptical orbit, its speed is always either increasing or decreasing. Can the acceleration be measured by means of a liquid level?

32. Calculate the change in t earth's temperature if the moon were to fall on it. Take the heat capacity of both bodies to be 1 cal/cm^3 deg.

33. Describe the distortions of the earth's orbit due to solar radiation pressure. Estimate their amount.

34. A load with mass M is suspended on a string passing through a pulley, and swings with a given amplitude, The end of the string is slowly moved a distance l (Fig. 1). Find the change in the period and in the amplitude of the swing, and calculate the work done.

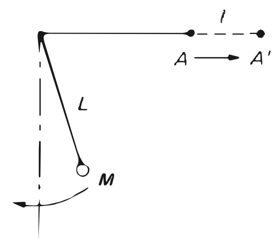


FIG. 1

35. How can the relation between the length and the period of a pendulum be found without calculation?

36. A car is moving with acceleration a up a hillside at angle α. Find the oscillation period of a pendulum (length l) inside the car.

37. Say which you think are the simplest and most exact experimental methods for using known physical constants and a standard of length (the metre) to generate a unit of time (the second) without using astronomical observations or the acceleration due to gravity (as if the experiment were being done in a deep mine-shaft or on another planet).

38. Determine the maximum range of audibility of a conversation in the open air.

39. Of an evening, on the river, one may find that a distant conversation is quite clearly audible. How does this happen?

40. A bell is hanging on a pillar at a height h. The wind speed is u. If the speed of sound is c, at what point on the ground will the sound of the bell be loudest?

41. Explain why there have been instances where the whole front end of a cannon has flown off when the cannon was fired.

42. Will a gardener watering a lawn with a hose always experience a reactive force?

43. Examine whether ultrasonic vibrations could in principle be used in an apparatus to form an image of objects under water.

44. List and describe all the methods of generating sound. Which of these is the most economical?

45. A conveyer belt carries loads horizontally, but has a transverse slope so that water can run off. The objects being carried lie free on the belt, but the friction is great enough to stop them from slipping sideways. The belt enters a building through a narrow slit in a perfectly smooth wall in a plane perpendicular to the direction of motion. What will be the movement of a cylinder lying free on the belt after it is carried against the wall? If it will in fact move, find the direction, speed, and acceleration of the motion, taking as given the slope of the belt to the horizontal, the speed of the belt, and the coefficient of friction between it and the cylinder.

46. Explain how a boy on a swing increases the amplitude of his movement.

47. What movement should be performed by a person rotating a hoop round his body?

48. Determine the damping of vibrations of a pendulum in a rarefied gas.

49. A motor-cyclist is riding on the wall of a barrel-shaped ring. Find the condition for this motion to be stable.

50. A hollow space in a pendulum is filled with a viscous liquid. Estimate quantitatively the effect of the liquid on the period and damping of the vibrations.

51. List the factors which affect the accuracy of a watch. Assess their relative importance.

52. The walls of a rectangular vessel are slowly brought together with relative speed v from an initial distance l. The vessel contains a particle whose speed relative to the earth is u. How does this speed vary with the time t? Assume that collisions with the walls are perfectly elastic.

53. The point of support of a pendulum is oscillating rapidly in a horizontal plane. Find the equilibrium position of the pendulum under gravity.

54. (*a*) Show that the vibrations of a pendulum can be maintained by causing the point of support to oscillate horizontally or vertically.

(*b*) Find the phase and period of these oscillations, and estimate the amplitude needed to maintain the vibrations for a simple pendulum.

(*c*) Examine the stability of these processes.

55. Two identical discs are placed a short distance apart. The upper disc is hung on a wire and can undergo torsional oscillations. The lower disc executes forced torsional oscillations with a specified amplitude, and a period equal to that of the free oscillations of the upper disc. The discs are put in a vessel containing a rarefied gas, in which the mean free path of the gas molecules is much longer than the linear dimensions of the vessel. Determine the form and amplitude of the steady oscillations of the upper disc relative to the lower one, and the time constant for the attainment of the final state.

56. Two identicial spheres of known mass, lying free on a perfectly smooth horizontal surface, are joined by a taut thread. A vertical rod moving horizontally at a constant speed strikes the thread. If the thread can be broken by a force F, what speed of the rod is necessary to break the thread? The part of the thread which receives the direct impact is strengthened.

57. The sound of an aircraft flying directly towards you and then away from you is recorded on tape. How can you determine its speed?

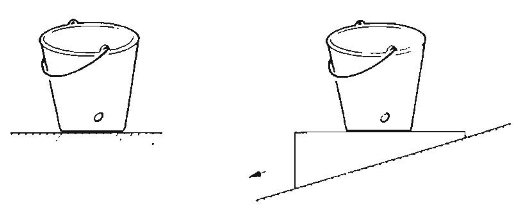
58. "Whispering gallery" waves are generated in a barrel-shaped open resonator. The resonator is rotating about its axis. How does the rotation affect wave propagation in the direction of rotation and in the opposite direction? Do beats occur, and at what frequency?

59. A bronze cylinder (radius R, length l, wall thickness h; $h/R \ll 1$) is suspended. What must be the size of the cylinder if its natural radial oscillation frequency f 2000 s^{-1}? Describe other possible types of oscillation, and estimate their frequencies.

60. By what experimental means could one determine the speed of propagation of universal gravity? what difficulties prevent this?

61. The surface of a river is an inclined plane. Can a body float freely down the river at a speed exceeding the maximum flow rate?

62. There are two identical buckets, each with a hole near the bottom (Fig. 2). One is standing on a horizontal table, the other on a wedge whose upper surface is also horizontal. From which bucket will the water leak faster if its original level is the same in both?



63. Why do door-screens protect doors from drifted snow?

64. A man is walking along a road at a speed u. On his chest is a newspaper of weight P. What is the minimum coefficient of friction to prevent the newspaper from slipping down? The air density is ρ and a wind blows against the man with speed v. His chest is regarded as a plane. How is the result changed for a convex chest? The area of the newspaper is S.

65. Explain why spray flies up when a stone or a raindrop falls on water. Does the height reached by the spray depend more on the size of the stone or on its speed of fall? What is the maximum possible height?

66. A trolley is running on rails with initial speed V_0. There is water in the hollow between the rails. The trolley carries a vertical pipe with a tap, dipping into the water and connected to another pipe with variable cross-section (Fig. 3). It is known that with a trolley speed V_0 and the tap closed, the water can rise in the vertical pipe to a level above that of the tap. Describe the movement of the trolley, neglecting friction.

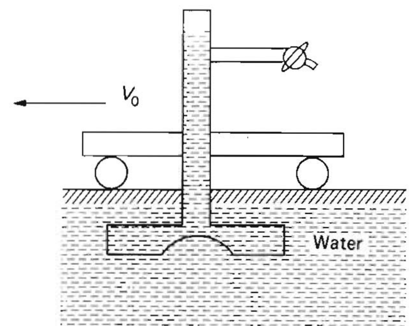


FIG. 3

67. How is work done by the exertion needed to turn a gyroscope about an axis perpendicular to that of the flywheel?

68. Why is the fork of bicycle handlebars set at an angle?

69. Four gyroscopes are placed on the sides of a square. Their ends are linked by hinges. The square is hung by one corner, and a load can be attached to the opposite corner (Kelvin's gyrospring). Determine the angular momentum of the gyroscopes such that the diagonal is lengthened by 1 cm when the side of the square is 30 cm and the load is 1 kg. How will the unloaded system move if the square retains its shape?

70. A gyroscope is placed on a swing so that its axis can turn in a plane through the axis of the swing. Describe how a person on the swing should turn the gyroscope so as to increase the amplitude of his movement. Find the most effective means of increasing the amplitude, and derive an expression for the rate of increase.

71. A load m is placed in a cylinder with radius R and mass M at a distance r from the axis. Describe how the cylinder will roll without slipping on a horizontal plane.

72. A top is rotating on a plane, with angular velocity ω, mass M, and moments of inertia A and B. It is struck by a bullet of mass m and speed v, which lodges in the top. Describe how the top may behave and how its behaviour can be used to find the speed of the bullet.

73. A heavy hoop with light spokes is placed in a vertical plane and can rotate about a horizontal axis through its centre. A particle whose mass is equal to that of the hoop is fixed into the rim. Determine the period of small oscillations of the resulting pendulum. How does the period vary if the pendulum is transferred to the moon or is placed in a frictionless liquid.

74. A rapidly rotating flywheel is placed on the end of a rod 1.5 m long standing vertically on the floor. Above the flywheel is a platform on which a person can stand. Calculate the size of the flywheel, for a speed of 3000 rpm, if the rod remains stable even when a person is doing gymnastics on the platform.

75. A given volume of gas is contained in a spherical metal vessel. Find the gas pressure for which the weight of the container is least.

76. Why can liquid nitrogen be poured on the hand without fear of 'burns'?

77. A vertical glass tube of circular cross-section is open at both ends. At the lower end is an electric heating coil carrying a current. Because the air is heated, a draught is set up. Assuming that the air flow in the tube is laminar, determine the temperature difference between the air outside and inside the tube, as a function of the length and radius of the tube and the electric power input. Neglect heat transfer through the glass.

78. What are the necessary initial and final conditions for partial liquefaction of a real gas by a single adiabatic expansion? Discuss the liquefaction of air as a numerical example.

79. What experiments can be devised to establish an absolute scale of temperature below 0.5 °K.

80. Estimate how thick the walls of a given material must be in order to keep the temperature of a room within 3 deg of its average over the year.

81. Calculate the mean temperature of the earth's surface, assuming that it radiates as a black body and that the energy of this radiation is in equilibrium with that from the sun. Assume that with vertical illumination 2 kW of solar energy is incident on 1 m^2 of the earth.

82. Estimate the height of fall during which a drop of molten lead will solidify.

83. Estimate the time for a pond to freeze.

84. There is a piece of ice on one pan of a balance, and a beaker of water on the other. The system is in equilibrium. The balance is covered with a large hood and the air is rapidly evacuated. Will the system still be in equilibrium?

85. Suppose that 4×10^9 years ago both the moon and the earth were surrounded by an atmosphere like the earth's present one. Estimate how the density of this atmosphere would vary during that time if the bodies moved in the solar system as they do now.

86. (*a*) Estimate the time needed to form visible droplets in a cloud chamber.

(*b*) Analyse and estimate the factors influencing the thickness of particle tracks in a cloud chamber.

87. Until electricity became widely available, a simple thermal air motor was used for low-power work, consisting of a water cooled cylinder, a continuously heated side-arm, and a piston operating a flywheel. Describe how and under what conditions such a motor functions.

88. It is known that, when coal is burned in steam boilers, only a fraction η $(T_1 - T_2)/T_1$ of each calorie can be converted into work, where T_1 and T_2 are the temperatures of the steam and the environment. The gas leaving the combustion chamber has a composition different from that of air. If it is mixed reversibly with air, a further amount of work can be obtained. Estimate the attainable limit to the increase of η, and devise possible cycles for carrying out this process.

89. Estimate the thermodynamic efficiency of the firing of cannon and hand-guns.

90. The reversible reaction of hydrogen iodide formation takes place in a mixture of hydrogen and iodine gases. Determine the quantity of hydrogen iodide formed, as a function of the initial quantities of the hydrogen and iodine, assuming the equilibrium constant known.

91. Two parallel plates are at a distance apart that is small compared with their transverse dimensions. Between them are several thin screens with good thermal conductivity. Determine the effect of the screens on the conduction of heat between the plates in two cases:

(*a*) when the mean free path of the gas molecules in the space between the plates is much less than the distance between the screens;

(*b*) when this mean free path is much greater than the distance between the plates.

92. In order to show that the viscosity of a gas is independent of the pressure, Maxwell observed the damping of torsional oscillations of a disc. Investigate how this damping will vary as the gas pressure falls.

93. A beam of molecules is created in a long horizontal tube. Matter enters the beam at normal temperature. At the other end of the tube, because the more slowly moving molecules undergo a greater deflection by gravity, a temperature difference may occur. Why is this consistent with the second law of thermodynamics?

94. If a beam of molecules is passed through a selector consisting of two parallel discs rotating on a common axis and having apertures that do not coincide, it is known that the faster molecules can be separated from the beam, as if by a Maxwell demon. How can this be reconciled with the second law of thermodynamics?

95. An aircraft is flying at about the speed of sound. The fuselage is heated by air friction. Estimate the maximum temperature to which the surface of the aircraft may be heated.

96. What is the change in the Debye temperatures of copper and solid helium-4 under hydrostatic compression at 1000 atm? Hooke's law is assumed valid.

97. There is a small hole with diameter 10^{-2} mm in a vessel where a vacuum of 10^{-5} mm Hg is to be maintained. Determine the size of the evacuation tube and the power of the vacuum pump.

98. In order to determine the charge on the electron in the classical experiments of Ehrenhaft and Millikan, a charged droplet of mercury is placed between the horizontal plates of a capacitor. The force of gravity on the droplet is balanced by the electric force, so that the electron charge can be found. Examine the effect of Brownian motion of particles on the accuracy of these measurements.

99. Determine the limiting size of plane circular discs of iron and aluminium (with thicknesses much less than their diameters) which are poorly wetted by water.

100. Two cylindrical communicating vessels with different diameters are filled with water or mercury and sealed. How will the total amount of the liquid be distributed between the vessels under conditions of weightlessness?

101. Calculate the time for the disappearance of a soap bubble connected to the atmosphere by a given capillary.

102. If a fishing-line is lowered into flowing water, a pattern of stationary capillary waves is formed round it. Explain this.

103. A bent tube has one end attached to a pump which delivers water at a constant pressure P. The maximum supply of water through the pump is Q ℓ/s. A plug of mass m is originally at rest in the horizontal part of the tube at a distance l from the open end (Fig. 4). At what speed will it emerge if the cross-section of the tube is S, the atmospheric pressure is p_0, and the friction between the tube and the plug is negligible.

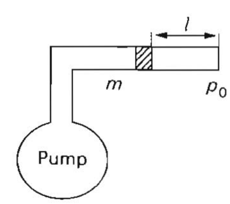


FIG. 4

104. Determine the speed at which a two-dimensional wave propagates on a stretched soap film of given thickness. Estimate the range of such speeds.

105. Find the potential at the centre of a metal sphere of radius R carrying a charge q.

106. Determine the depth of penetration of seasonal temperature variations into the earth's crust, using the thermal conductivity of granite. Calculate also the amplitude of the seasonal temperature fluctuations at the bottom of Lake Baikal.

107. An insulated copper ball of given radius, covered with a known amount of polonium, is placed in a vacuum. Because of the emission of α particles it acquires a charge. Determine the way in which the potential increases with time, and its limiting value.

108. An insulated sphere of caesium metal, having a given size, is placed in a vacuum, exposed to daylight on one side, and given a charge by the photoelectric effect. Estimate the variation of its potential with time.

109. Figure 5 shows an electrostatic machine of the droplet type. Water droplets charged to a given potential fall from a tube into a hollow insulated metal sphere. Determine the limiting potential to which the sphere is charged, as a function of the height of fall.

110. A free soap bubble is electrified to the maximum possible potential, limited by the breakdown strength of the air around it; how and by what amount is its radius changed?

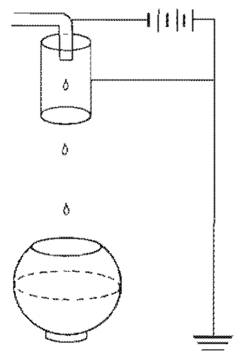


FIG. 5

111. A clock operated by radioactive energy consists of a small amount of radioactive substance on the rod of a leaf electroscope. The radiation and the loss of charge cause the electroscope to be continuously charged, and the leaves diverge; on reaching a certain angle they touch an earthed contact and fall back to their initial position. Calculate the design of such a clock with a period of 1 minute. Estimate its possible accuracy.

112. A small metal cylinder of given size is swinging longitudinally with frequency ω. Assuming that electrons move freely in the metal, calculate the charges formed on the ends. Make a similar calculation for an insulating rod with permittivity ε.

113. A dielectric plate is in a uniform electric field. Determine the torque on the plate.

114. The horizontal plates of a plane capacitor are connected to a battery giving a constant emf E. A charged ball between the plates is suspended in the gravitational field. How will it move when the distance between the plates is changed?

115. Why are electromagnetic machines and not electrophorus-type ones used in practice to generate high power?

116. If one end of a conductor is at a positive potential and the other at a negative potential, a current must flow along it from plus to minus. Why then does the lamp not light in the open circuit shown in Fig. 6?

117. What limits the sensitivity of a string electrometer, and what is the value of the sensitivity?

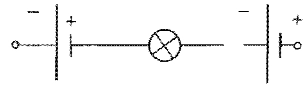


FIG. 6

118. Examine the possibility of an experiment to determine the interaction of an electron with the earth's gravitational field.

119. Thermal devices for electrical measurement are often designed as in Fig. 7. A current is passed along a thin stretched wire ab. The wire becomes heated and lengthens, and is curved by the action of the spring. The thread leading to the spring is passed through a cylinder fixed to the pointer. Find the relation between the deflection of the pointer and the strength of the current. Estimate the condition for the maximum sensitivity of such an instrument for a given current.

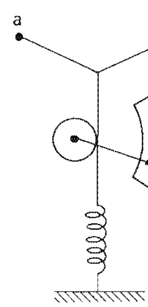


FIG. 7

120. An incandescent lamp is supplied with alternating current. How does the filament temperature vary with time? Estimate the dependence of the variations of this temperature on the filament thickness, material, and so on.

121. An ordinary 50-watt incandescent lamp is supplied with alternating current from the mains. Estimate the amplitude of the fluctuations of light intensity in the visible region of the spectrum if the bulb is filled with argon.

122. A Wheatstone bridge operating on direct current is in balance. An alternating current is passed through one arm. Investigate the effect on the balance of the bridge if the strength of the alternating current is such that Ohm's law is not satisfied.

123. In an electrical substation which supplies power to several houses, the ammeter and the voltmeter are inadvertently interchanged, and the generator is then switched on. What will be the result in the substation?

124. An electron is describing a circular orbit in a magnetic field in vacuum. On a section of the path, two grids are placed, having a potential difference such that the speed of the electron is changed whenever it passes between them. Under what conditions will the speed increase?

125. If a horizontal conductor is moved at right angles to its length, a potential difference occurs between its ends, because of the earth's magnetic field. Calculate this potential difference, and discuss whether it could be used in practice to determine the rate of motion of aircraft, ships and satellites relative to the earth.

126. A satellite is moving in the earth's magnetic field. What electromagnetic effects can result? Describe them and estimate their magnitude, assuming the field to be that of a uniformly magnetized sphere.

127. Describe the electrical effects caused by the earth's magnetic field when water having an electrical conductivity flows in rivers.

128. The following method is proposed for the investigation of liquid flow rates. The liquid is made conducting by means of impurities, and the flow takes place in a magnetic field. At the point where the speed is to be determined, a probe consisting of two conductors is placed, and the potential difference between them is observed. Investigate the practicability of this method.

129. A current pulse I is passed through a thin wire of diameter d. After a time t, the wire disintegrates. Calculate the magnetic field, and estimate the maximum field that can be thus obtained and the duration of its existence.

130. Two parallel wires are stretched between the poles of a magnet, and a conducting plate lies freely upon them. Describe the motion of the plate when a capacitor with capacitance C charged to a potential V is discharged through the circuit formed by the two wires and the plate. The magnetic field is vertical, at right angles to the plane of the circuit.

131. A lightning-conductor is earthed through a circular copper tube of diameter 2 cm and wall thickness 2 mm. After a lightning flash, the tube has become a circular rod. Explain this behaviour, and estimate the discharge current.

132. Estimate the minimum cross-section of a copper lead, the source power, and the energy consumption needed to compensate the earth's magnetic field by means of an electric current.

133. Calculate the efficiency of screening of the earth's magnetic field by a hollow sphere of thickness d and radius R. Compare the efficiency of such shields made of iron and of Permalloy.

134. Discuss whether a ballistic galvanometer or a fluxmeter gives a more accurate measurement of a magnetic field.

135. Determine the strength of the magnetic field created by rapid rotation of a copper cylinder. Show that this effect cannot account for terrestrial magnetism.

136. Discuss the possibility of confining a neutron in a magnetic field.

137. A long thin-walled copper cylinder undergoes forced oscillations about its principal axis. Because of their inertial mass, the free electrons in the metal lag in phase behind the oscillations of the cylinder, and an alternating magnetic field is formed in it. Calculate the field, and assess the possibility of measuring it by experiment.

138. When the current in the primary circuit of a transformer is interrupted, there is no overvoltage in the secondary circuit, but in an induction coil there is. Why?

139. A square voltage pulse is applied to the primary terminals of a transformer. How will it be modified at the secondary terminals, depending on the properties of the transformer.

140. A coil containing a permanent magnet is connected to a capacitor. The self-inductance of the coil, the capacitance of the capacitor, and the magnetic flux due to the magnet, are known. Describe the electrical process which occurs in the circuit when the magnet is very quickly removed from the coil and when it is very slowly removed. In each case, determine the work done in removing the magnet.

141. A current I flows in a wire loop of radius r. Find the maximum force exerted on a small magnet with moment m lying along the axis of the loop (Fig. 8).

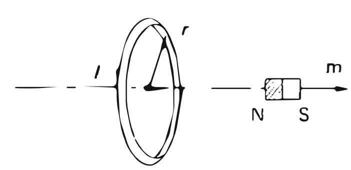


FIG. 8

142. The dimensions of a solenoid and the current through it are given.

If it is placed vertically, estimate the dimensions and position of an iron core that is drawn into it from below with the maximum force.

143. A superconducting solenoid is 300 cm long with internal diameter 50 cm; the field is 60 kOe. A steel girder with cross-section 200 cm^2 is placed above the solenoid at 150 cm from its axis. The length of the girder is much greater than that of the solenoid, and it is parallel to the axis of the latter. Estimate the force attracting it to the solenoid.

144. A conducting cylinder passes through a solenoid carrying a current. Determine the condition for the magnetic field to prevent its passage. The ohmic resistances of the cylinder and the solenoid may be neglected.

145. A magnetic gun on the following principal is proposed. A cylinder (the projectile) is placed close to a solenoid and on its axis. A current is suddenly passed through the solenoid, When the cylinder, moving under the attraction, reaches the middle of the solenoid, the current is automatically cut off. Estimate the initial projectile velocity that can be achieved with such a gun, and the generator power necessary.

146. Find the conditions of equilibrium for a superconducting sphere in the magnetic field of a horizontal circular loop carrying a current.

147. A long cylindrical superconductor is placed in a uniform magnetic field so that its axis is perpendicular to the field. Determine the strength and direction of the magnetic field on the surface of the superconductor.

148. How can the maximum discharge power be obtained from a capacitor with a given capaci tance charged to a given potential?

149. What will be the saving in weight and volume of the structure if a given amount of electrical energy is stored in a superconducting solenoid rather than in a capacitor?

150. What fraction of the energy is converted into sound in the discharge of a Leyden jar?

151. There are six push-buttons. When none of them is pressed, a lamp remains unlit. When buttons 1, 2, and 5 are simultaneously pressed, the lamp lights. No other combination of buttons can be pressed so as to light the lamp. Draw a diagram of the simplest electric circuit having these properties.

152. A superconducting solenoid consists essentially of copper with a volume occupation factor of 0.5. The outer diameter is 10 cm, the inner diameter 2 cm, and the height 15 cm. The internal field is 50 kOe. The superconductivity of the winding is suddenly destroyed. Find the resulting temperature of the copper.

153. A wire solenoid is connected to a battery. How will the current in the circuit change when the wire is suddenly straightened?

154. The values of L and C in an oscillator circuit are known. Estimate the minimum current for which it will give detectable oscillations.

155. An electron beam at a potential of 1000 V is generated in a cathode-ray oscillograph. The beam is deflected by a capacitor over a distance of 2 cm. Describe how the screen will register a square pulse applied to the oscillograph with a line rise time of 0.01 nanosecond.

156. A simple electroscope has the principal dimensions shown in Fig. 9. The gold leaf is 2 cm long and 0.1 μm thick. Estimate the leaf divergence angle α when the electroscope is charged to 300 V.

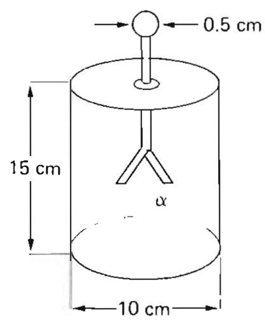


FIG. 9

157. Evaluate the possibility of detecting a fast charged particle from the inductive effect in a capacitor, coil or resonator.

158. A single layer of wire with square cross-section is wound on a uniform circular iron core of given size covered with a uniform insulating layer. A constant current is passed through the wire. Describe what happens when the current suddenly ceases, and estimate the overvoltage at the ends of the winding. Calculate the size of such an apparatus to carry 100,000 V.

159. A conducting cylinder is surrounded by a long single-layer solenoid, with a small gap between them. Show that the rate of electric wave propagation in such a system is about equal to the speed of light multiplied by the ratio of the length of the solenoid to the length of the winding.

160. If an insulated permanent magnet is charged to a certain potential, there will exist around it both a constant electric field E and a magnetic field H, and the Poynting vector S $c\mathbf{E} \times \mathbf{B}/4\pi$ will not be zero. What electromagnetic radiation corresponds to this vector?

161. Air is in a sealed tube at a given pressure and temperature. One end of the tube is placed in a uniform magnetic field. Owing to the paramagnetism of oxygen, its concentration is no longer constant along the tube.

(*a*) Estimate the variations in the concentration along the tube.

(*b*) Estimate the time constant of the process.

(*c*) Discuss the possibilities of using this process to separate oxygen from air.

162. A cylindrical vessel containing a liquid mixture of oxygen and nitrogen at normal pressure is placed in a solenoid so that one end is at the centre and the other outside. Determine the hydrostatic pressure in the liquid for various concentrations of the mixture, if the field within the solenoid is 300 kG.

163. Honda found by experiment that graphite has three different values of the magnetic susceptibility in the direction of the principal crystallographic axis and the two directions perpendicular to it. Show that this can occur only if the graphite contains ferromagnetic impurities.

164. What is the resistance of a thin metal wire with diameter d and a mirror surface, expressed in terms of the bulk properties of the metal? Assume that the mean free path $\lambda \gg d$.

165. The following experiment is used to demonstrate the existence of the Curie point in ferromagnets. A star A whose rays are made of a ferromagnetic material can revolve on a pivot near a permanet magnet B (Fig. 10). If a burner C is placed next to the magnet, the star begins to move. Estimate the thermodynamic efficiency of this motor.

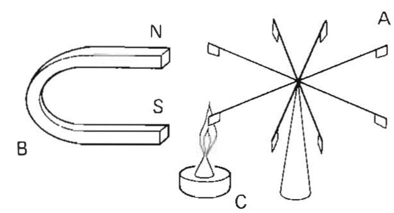


FIG. 10

166. Calculate the temperature reached by the paramagnetic salt $NH_4Fe(SO_4)_2 \cdot 12H_2O$ after demagnetization from 20 kOe to 100 Oe, assuming that the same obeys Curie's law at all temperatures concerned, and that the spin lattice relaxation time is much greater than the demagnetization time. The initial temperature is $1\,^\circ K$.

167. How does a magnetic field of 140 kOe affect the Curie point and the temperature dependence of the magnetization in nickel?

168. How could electric, magnetic and other forces be used to suspend a body freely, in stable equilibrium with gravity(Muhammad's coffin)?

169. A cylindrical permanent magnet is in suspension above a superconducting plane (Arkad'ev's experiment). Calculate the distance between them.

170. A cylindrical permanent magnet, magnetized along its axis, is in stable suspension above a plane surface of a superconductor. Find the range of frequencies of natural vertical oscillations of the magnet.

171. According to research by Ayrton, the field in an electric arc is $E = a + b/i$, where a and b are constants, and i the current. Discuss the stability of the arc as a function of the applied voltage.

172. What will be the apparent colour of a red liquid if the vessel containing it is immersed in one containing a blue liquid?

173. Describe the reflection of white light from the side of a soap bubble as a function of the bubble size and the film thickness.

174. Consider the possibility of constructing an optical instrument with which a Lippmann photograph could be viewed so that both eyes saw it in the same colours.

175. What quantity of water droplets is present in a cubic centimetre of fog if the visibility is 100 m and the fog persists for about an hour?

176. There is still a strong smell of tobacco in a room 1 hour after a meeting. A ray of sunlight entering the room is scattered to the extent of 10^{5} per cm. Estimate the smoke content of the air.

177. How does the absorption of electromagnetic waves in a plasma depend on the magnetic field? (The wave propagates along the field.)

178. Determine the energy loss from an electron beam with energy 1 keV passing through a hydrogen plasma at a temperature of $3 \times 10^4\,^\circ K$ and a pressure of 1 atm.

179. An electron beam in a vacuum, with energy 10^4 eV and current 1 A, travels along a magnetic field of 10^3 Oe. What is the smallest cross-section of the beam that then remains unaffected?

180. What is the highest possible temperature, and how can it be obtained, from the sun's radiation at the focus of a converging lens or mirror? How does this temperature compare with

that of the sun?

181. A glass vessel filled with oxygen under pressure is now in use as a flash bulb for snapshots. The vessel contains an aluminium foil ignited by a heated wire. Estimate the quantity of visible light emitted. (The candidate is shown such a flash bulb.)

182. How does a copper sphere cool in cosmic space?

183. Estimate the distance from the point of impact at which a V2 missile could be detected bolometrically, assuming that it has a speed of 1 km/s, a length of 15 m, and a diameter of 2 m.

184. Discuss the thermal radiation from a hot diffraction grating.

185. Investigate whether there is an optimum size for the pinhole in a lensless camera.

186. Would the resolving power of a neutron microscope be greater than that of an electron microscope? Discuss the fundamental difficulties of constructing a neutron microscope.

187. Discuss how to obtain the sharpest and most contrasted silhouette from a given object and a given light source.

188. Sketch the interference pattern formed on a screen by four small holes at the corners of a small square. Assume that the screen is at a considerable distance from the holes and that a plane wave is incident.

189. Radiation from a laser passes through a two-beam interferometer in such a way that one beam travels along a solenoid. Estimate the smallest change in the speed of light, caused by the magnetic field of the solenoid which could be detected from the shift of the interference bands.

190. Radio aerials, n in number, are arranged parallel and equidistant on a plane. The maximum intensity is to be obtained at a given point O, whose distance is much greater than the wavelength λ. How should the distance between the aerials and the phase relation between their oscillations be chosen so as to achieve this? By what factor will the intensity at O exceed that from one aerial?

191. What should be the rate of rotation of a body so that the absorption and emission of radiation by its atoms should allow the most sensitive optical detection of a phenomenon analogous to the Zeeman effect?

192. An infinite number of particles are present in space. One particle A is at rest; all the others are moving away from it in various directions, with speeds proportional to their distances from A. An observer is located on another particle, B. What will he observe to be the pattern of motion of the remaining particles?

193. A linear accelerator forms an electron beam at 15 MV with power 2 MW. A ruby laser beam is sent in the opposite direction. Describe the scattering of light by the electrons.

194. Find how the composition and pressure of the gas affect the speed of rotation of the vanes in a Crookes radiometer.

195. An electron describes a circular orbit of radius r at a given speed v in a uniform magnetic field H. How does its motion change if the field is slowly changed by an amount ΔH? Can this chance be compensated by placing a charge e at the centre of the orbit.

196. A snow avalanche builds up as it rolls without slipping down a mountain with height $H = 1$ km and a slope of 45° (Fig. 11). Find the speed of the avalanche at the foot of the mountain.

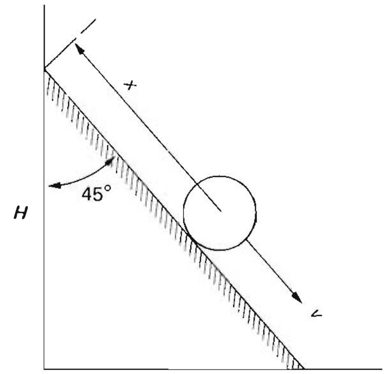


FIG. 11

197. A device resembling a siren diaphragm is placed at one end of a long cylindrical tube a few centimetres in radius. The other end of the tube is left open. The diaphragm opens an aperture for gas flow, with a frequency of the order of 10^3 Hz. Describe the wave motion and the temperature of the gas in the tube, and estimate the characteristic damping of the wave. How does the oscillation energy depend on the gas pressure in front of the diaphragm? Suggest possible designs of the diaphragm.

198. Gymnasts increase the height of a jump by repeated rebounds from a trampoline (a horizontal surface with a spring suspension). Calculate the most effective design of the trampoline springs, and determine what it is that limits the height of the jump.

199. A person could walk on the ceiling, like a crawling fly, if his feet were adhesive. With an iron ceiling, this could be achieved by means of magnetic shoes. Give a design and calculation for these.

200. Two satellites have a head-on collision. Describe the subsequent events.

201. Describe what determines the accuracy of focusing of an electron beam. What is this accuracy in a present day television set?

202. Estimate the height to which a person can pole vault. Determine the cross-section of the pole.

203. How can the mass of a meteorite, assumed to consist of antimatter, be estimated from the area of destruction or the size of the crater that it makes?

204. At what pressure will air at room temperature become 1 percent ionized? Can this occur under laboratory conditions?

205. What power would be needed to demagnetize the earth by means of the current in a cable along the equator? Consider the relationship between the result and the nature of the earth's magnetism. Determine the cross-section of the cable, assuming it to be a superconductor.

206. N spheres of diameter D are placed in a line at a distance l apart. The first sphere is struck so as to give it a speed v. Calculate the initial speed of movement of the sphere at the far end of the row, and estimate the time that has elapsed since the first sphere was struck. Discuss the problem for two cases: (*a*) tennis balls, (*b*) billiard balls. Neglect rotation of the balls and surface friction.

207. A small crucible in a vacuum contains an evaporating mixture of cadmium isotopes. The vapour passes through a diaphragm, and a molecular beam is formed. This passes through two discs with peripheral holes. These discs are on a common axis and are rotating at a high speed (Fig. 12). Estimate what degree of isotope separation can be achieved in this way, if the beam molecules have a Maxwellian velocity distribution.

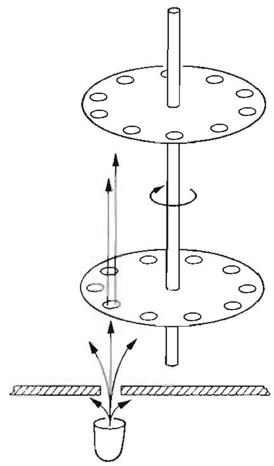


FIG. 12

208. A Van de Graaff generator gives 5×10^6 V at 15 atm pressure in nitrogen. Estimate the belt width needed to yield a power of 1 kW.

209. In the turbocompressor of our nitrogen liquefaction plant, the rotor has an angular speed ω 18,000 rpm, and is balanced with accuracy δ 0.01 mm. The rotor mass $m = 100$ kg; the mass of the compressor with its base plate (fixed to the ground) is $M = 3$ t. Determine what springs are needed under the base plate to reduce the vibration in the building by a factor of 100.

210. A student comes late into a lecture-room. She is wearing a strong perfume, Estimate the time that elapses before the lecturer can detect the scent of the perfume.

211. Determine the power of a ruby laser that can burn a hole in a sheet of paper.

212. A cylindrical magnet of length l 10 cm and diameter d 1 cm is placed at a distance $h = 1$ cm above a horizontal plane and parallel to it. The magnet turns about a vertical axis through its centre. Calculate the energy dissipation in the plane if it is made of copper. The magnetization of the magnet is F 1 T, and the angular velocity of rotation $\omega = 10^4\ s^{-1}$.

213. Night-watchmen in former times, to show malefactors that they were not asleep, had rattles consisting of a small board with a handle at one end and a string of length l at the other end, carrying a ball of mass m (Fig. 13). Find the movement of the handle that will make the ball strike the board with period T.

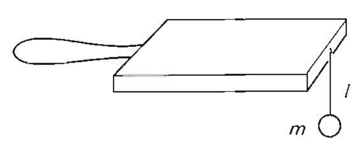


FIG. 13

214. A cylindrical dewar is filled with liquid oxygen. On the bottom of the dewar is a small heater from which gas bubbles rise. In their path is a region where there is a strong magnetic field. Describe how the shape of the bubbles will change as they pass through this region.

215. A mixture of helium gas with 10 percent argon flows between two planes at a distance $a = 1$ mm apart over a distance $l = 10$ cm. The planes are cooled to liquid helium temperature, and absorb only argon. Assuming this absorption to be complete, estimate the gas flow rate needed to make the helium 99.99 percent pure.

216. A boat carries a wind motor of the windmill type, which drives the propeller screw. Discuss the possibility that such a boat can sail against the wind.

217. An eclipse of the sun is usually observed through smoked glass. Estimate the necessary thickness of soot.

218. A hollow sphere of diameter D 2 cm has a hole of diameter $d = 0.1$ cm. In front of the hole is a lens with diameter $A = 20$ cm and focal length $F = 20$ cm. The lens is placed so that the image of the sun is on the hole. Estimate the temperature corresponding to the radiation intensity in the sphere if its inner surface is (a) perfectly reflecting, (b) silvered.

219. A horizontal magnetic field is set up in the gap between two circular magnetic poles. Estimate the speed of fall through the gap for a copper plate whose area is much greater than the pole cross-sections.

220. Explain why a badly inflated car tyre does not run smoothly. Describe and estimate the losses when a pneumatic tyre oscillates.

221. A voltaic arc is supplied with direct current which can be modulated at a particular frequency. Estimate the intensity of sound emitted as a function of the frequency range and the modulation amplitude.

222. Find the speed at which a small car can overturn as it takes a 90° bend.

223. Estimate the work needed to drive a needle of radius r through a rubber sheet of thickness d.

224. A capacitor is discharged through a copper wire of length $l = 2$ cm and radius $r = 0.01$ mm. Estimate the maximum azimuthal magnetic field that can be obtained at the surface of the wire at the instant when the wire disintegrates.