200 Puzzling Physics Problems is aimed at strengthening a student's grasp of the laws of physics by applying them to situations that are practical and to problems that yield more easily to intuitive insight than to brute-force methods and complex mathematics. The problems are chosen almost exclusively from classical (i.e. non-quantum) physics, but are no easier for that. For the most part, these problems are intriguingly posed in accessible non-technical language. This requires the student to select the right framework in which to analyse the situation and to make decisions about which branches of physics are involved. The general level of sophistication needed to tackle most of the 200 problems is that of the exceptional school student, the good undergraduate or the competent graduate student. The book should be valuable to undergraduates preparing for 'general physics' papers, either on their own or in classes or seminars designed for this purpose. It is even hoped that some physics professors will find the more difficult questions challenging. By contrast, the mathematical demands made are minimal, and do not go beyond elementary calculus. This intriguing book of physics problems should prove not only instructive and challenging, but also fun.

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Preface

In our experience, an understanding of the laws of physics is best acquired by applying them to practical problems. Frequently, however, the problems appearing in textbooks can be solved only through long, complex calculations, which tend to be mechanical and boring, and often drudgery for students. Sometimes, even the best of these students, the ones who possess all the necessary skills, may feel that such problems are not attractive enough to them, and the tedious calculations involved do not allow their 'creativity' (genius?) to shine through.

This little book aims to demonstrate that not all physics problems are like that, and we hope that you will be intrigued by questions such as:

- How is the length of the day related to the side of the road on which traffic travels?
- Why are Fosbury floppers more successful than Western rollers?
- How far below ground must the water cavity that feeds Old Faithful be?
- How high could the tallest mountain on Mars be?
- What is the shape of the water bell in an ornamental fountain?
- How does the way a pencil falls when stood on its point depend upon friction?
- Would a motionless string reaching into the sky be evidence for UFOs?
- How does a positron move when dropped in a Faraday cage?
- What would be the high-jump record on the Moon?
- Why are nocturnal insects fatally attracted to light sources?
- How much brighter is sunlight than moonlight?
- How quickly does a fire hose unroll?

- How do you arrange two magnets so that the mutual couples they experience are not equal and opposite?
- How long would it take to defrost an 8-tonne Siberian mammoth?
- What perils face titanium-eating little green men who devour their own planet?
- What is the direction of the electric field due to an uniformly charged rod?
- What is the catch in an energy-generating capacitor?
- What is the equivalent resistance of an *n*-dimensional cube of resistors?
- What factors determine the period of a sand-glass egg timer?
- How does a unipolar dynamo work?
- How 'deep' is an electron lying in a box?

These, and some 180 others, are problems that can be solved elegantly by an appropriate choice of variables or coordinates, an unusual way of thinking, or some 'clever' idea or analogy. When such an inspiration or eureka moment occurs, the solution often follows after only a few lines of calculation or brief mental reasoning, and the student feels justifiably pleased with him- or herself.

Logic in itself is not sufficient. Nobody can guess these creative approaches without knowing and understanding the basic laws of physics. Accordingly, we would not encourage anybody to tackle these problems without first having studied the subject in some depth. Although successful solutions to the problems posed are clearly the principal goal, we should add that success is not to be measured by this alone. Whatever help you, the reader, may seek, and whatever stage you reach in the solution to a problem, it will hopefully bring you both enlightenment and delight. We are sure that some solutions will lead you to say 'how clever', others to say 'how nice', and yet others to say 'how obvious or heavy-handed'! Our aim is to show you as many useful 'tricks' as possible in order to enlarge your problem-solving arsenal. We wish you to use this book with delight and profit, and if you come across further similar 'puzzling' physics problems, we would ask you to share them with others (and send them to the authors).

The book contains 200 interesting problems collected by the authors over the course of many years. Some were invented by us, others are from the Hungarian 'Secondary School Mathematics and Physics Papers' which span more than 100 years. Problems and ideas from various Hungarian and international physics contests, as well as the Cambridge Colleges' entrance examination, have also been used, often after rewording. We have also been guided by the suggestions and remarks of our colleagues. In particular, we would like to thank Masaaki Kato for several helpful observations and suggested clarifications and Alfonso Diaz-Jimenez for an interesting note on the launching of space probes (see solution 17). It is impossible to determine the original authors of most of the physics problems appearing in the international 'ideas-market'. Nevertheless, some of the inventors of the most puzzling problems deserve our special thanks. They include Tibor Bíró, László Holics, Frederick Károlyházy, George Marx, Ervin Szegedi and István Varga. We thank them and the other people, known and unknown, who have authored, elaborated and improved upon 'puzzling' physics problems.

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How to use this book

The following chapter contains the *problems*. They do not follow each other in any particular thematic order, but more or less in *order of difficulty*, or in groups requiring *similar methods of solution*. In any case, some of the problems could not be unambiguously labelled as belonging to, say, mechanics or thermodynamics or electromagnetics. Nature's secrets are not revealed according to the titles of the sections in a text book, but rather draw on ideas from various areas and usually in a complex manner. It is part of our task to find out what type of problem we are facing. However, *for information*, the reader can find a list of topics, and the problems that more or less belong to these topics, on the following page. Some problems are listed under more than one heading. The symbols and numerical values of the principal physical constants are then given, together with astronomical data and some properties of material.

The majority of the problems are not easy; some of them are definitely difficult. You, the reader, are naturally encouraged to try to solve the problems on your own and, obviously, if you do, you will get the greatest pleasure. If you are unable to achieve this, you should not give up, but turn to the relevant page of the short *hints* chapter. In most cases this will help, though it will not give the complete solution, and the details still have to be worked out. Once you have done this and want to check your result (or if you have completely given up and only want to see the *solution*), the last chapter should be consulted.

Problems whose solutions require similar reasoning usually follow each other. But if a particular problem relates to another elsewhere in this book, you will find a cross-reference in the relevant hint or solution. Those requiring especially difficult reasoning or mathematically complicated calculations are marked by one or two *asterisks*.

Some problems are included whose solutions raise further questions that are beyond the scope of this book. Points or issues worth further consideration are indicated at the end of the respective solutions, but the answers are not given.

Thematic order of the problems

Kinematics: 1, 3, 5, 36, 37, 38*, 40, 41, 64, 65*, 66, 84*, 86*.
Dynamics: 2, 7, 8, 12, 13, 24, 32*, 33, 34, 35, 37, 38*, 39*, 70*, 73*, 77, 78*, 79*, 80**, 82, 83, 85**, 90, 154*, 183*, 184*, 186*, 193*, 194.
Gravitation: 15, 16, 17, 18, 32*, 81**, 87, 88, 109, 110*, 111*, 112*, 116, 134*.
Mechanical energy: 6, 7, 17, 18, 32*, 51, 107.
Collisions: 20, 45, 46, 47, 48, 71, 72*, 93, 94, 144*, 194, 195.
Mechanics of rigid bodies: 39*, 42**, 58, 60*, 61**, 94, 95*, 96, 97*, 98, 99**.
Statics: 9, 10*, 11, 14*, 25, 26, 43, 44, 67, 68, 69*.
Ropes, chains: 4, 67, 81**, 100, 101*, 102**, 103*, 104*, 105**, 106*, 108**.
Liquids, gases: 19, 27, 28, 49*, 50, 70*, 73*, 74, 75*, 91*, 115**, 143, 200.
Surface tension: 29, 62, 63, 129, 130*, 131*, 132**, 143, 199*.
Thermodynamics: 20, 21*, 133, 135**, 136, 145, 146*, 147, 148.
Phase transitions: 134*, 137*, 138, 140*, 141*.
Optics: 52, 53, 54, 55, 56, 125*, 126, 127, 128*.
Electrostatics: 41, 90, 91*, 92, 113*, 114, 117*, 118, 121, 122, 123*, 124*, 149, 150, 151*, 152, 155, 156, 157, 183*, 192*, 193*.
Magnetostatics: 89**, 119, 120**, 153*, 154*, 172, 186*.
Electric currents: 22, 23, 158, 159, 160*, 161, 162*, 163*, 164*, 165, 169, 170*, 172.
Electromagnetism: 30, 31, 166, 167, 168*, 171*, 173*, 174*, 175*, 176, 177, 178*, 179, 180, 181*, 182*, 184*, 185*, 186*, 187*.
Atoms and particles: 93, 188, 189*, 190*, 191, 194, 195, 196, 197*, 198*.
Dimensional analysis, scaling, estimations: 15, 57, 58, 59*, 76*, 77, 126, 139, 142, 185*, 199*.

*, ** A single or double asterisk indicates those problems that require especially difficult reasoning or mathematically complicated calculations.

Physical constants

Gravitational constant, G	$6.673 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$
Speed of light (in vacuum), c	$2.998 \times 10^{8}\,\mathrm{m\,s^{-1}}$
Elementary charge, e	$1.602 \times 10^{-19}\,\mathrm{C}$
Electron mass, m_e	$9.109 \times 10^{-31}\,\mathrm{kg}$
Proton mass, m_p	$1.673 \times 10^{-27}\,\mathrm{kg}$
Boltzmann constant, k	$1.381 \times 10^{-23}\,\mathrm{J\,K^{-1}}$
Planck constant, h	$6.626 \times 10^{-34}\,\mathrm{J\,s}$
Avogadro constant, N_A	$6.022 \times 10^{23}\,\mathrm{mol^{-1}}$
Gas constant, R	$8.315\,\mathrm{J\,mol^{-1}K^{-1}}$
Permittivity of free space, ε_0	$8.854 \times 10^{-12}\,\mathrm{C\,V^{-1}\,m^{-1}}$
Coulomb constant, $k = 1/4\pi\varepsilon_0$	$8.987 \times 10^{9}\,\mathrm{V\,m\,C^{-1}}$
Permeability of free space, μ_0	$4\pi \times 10^{-7}\,\mathrm{V\,s^2\,C^{-1}\,m^{-1}}$

Some astronomical data

Mean radius of the Earth, R	6371 km
Sun–Earth distance (Astronomical Unit, AU)	1.49×10^{8} km
Mean density of the Earth, ρ	$5520\,\mathrm{kg\,m^{-3}}$
Free-fall acceleration at the Earth's surface, g	$9.81\,\mathrm{m\,s^{-2}}$

Some physical properties

Surface tension of water, γ	$0.073\,\mathrm{N\,m^{-1}}$
Heat of vaporisation of water, L	$2256\,\mathrm{kJ\,kg^{-1}} = 40.6\,\mathrm{kJ\,mol^{-1}}$
Tensile strength of steel, σ	500–2000 MPa

Densities[a], ρ (kg m^{-3})

Hydrogen	0.0899	Titanium	4510
Helium	0.1786	Iron	7860
Air	1.293	Mercury	13 550
Water (at 4 °C)	1000	Platinum	21 450

[a] Densities quoted in normal state.

Optical Refractive Indices[b], n

Water	1.33	Glass	1.5–1.8
Ice	1.31	Diamond	2.42

[b] At $\lambda = 590$ nm.