Physics for IIT-JEE VOL. II

HALLIDAY / RESNICK / WALKER

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Manish K. Singhal

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Dedication

This book is dedicated to my loving teacher,
***Prof. P.V. Krishnan** (retired professor, IIT Delhi), and his wife,*
*mother **Krishangi Devi**, whose teachings gave me life.*
Whatever I am today, I owe it to them.

Preface

Having experienced teaching at various levels and with a varied group of students, I have experienced the shortcomings faced by most of the students. I can also remember my own experiences of failure and dejection when I used to study. Often, I did not find answers to my questions, or I could not find a book that could help me think, nor did I find a collection of problems that stimulate the mind. In this book, finally I have come to fulfill a vision of a book that has *an international collection of problems, the theory to such depth as we cover at Bansal Classes, Kota, and American quality of printing*. This book is not a substitute for a teacher. I strictly believe and this has been proven over the years: To learn, you need a teacher. But learning under a qualified teacher will help you understand this book better.

Often students find Physics tough or at least challenging. Perhaps it is both because it tries to encourage you to think and it does not follow any stereotyped pattern. A thinking individual will do well in physics. In the modern learning atmosphere, perhaps we are never even encouraged to think. I have made an attempt to cross this barrier and challenge you to think at numerous places. For this purpose, I have scattered numerous checkpoints throughout the chapters. The problem section begins with a set of assertions and reason problems, and the student is required to find whether those statements are correct or not. And if they are, what are the reasons.

Those of you who are accustomed to the original Halliday, Resnick, and Walker would be in for a surprise because although this is supposed to be an adaptation, I have freely made the changes as per the needs of the students who are appearing in competitive examinations like Physics Olympiads, IIT JEE, and so on. So the net result is that you have an altogether new book, my style. Three new chapters have been added and many have been deleted. All over the world, slowly objective type examinations are replacing subjective papers. So we have added extensive collection of objective problems on each and every concept covered in chapter. Each chapter has been started with a chapter opener which illustrates real world phenomena based on that chapter. Some of them are fun, and some of them are real phenomena which should set your mind thinking.

The book follows a particular format. I introduce a concept and try to illustrate it by the means of an example. In the spirit of what we did in Volume I of this book, we have explained each illustration in four sections: Conceptualize, classify, compute, and conclude.

- **Conceptualize** explains the problem with a clue to the solution.
- **Classify** contains details of the principles of physics used to solve the problem.
- **Compute** gives the detailed solution.
- The real punch lies in the **conclude** section where many a times the student has to think on the lines of great physicists.

In the exercises that follow at the end of each chapter, I am trying to take the students through the same ideas. The spirit of the book will be marred if the student just focuses on the theory and does not try out the exercises that follow. I have tried to arrange the exercises in increasing order of difficulty. The answers are given at the end of the chapter. If one is not able to solve a particular question, then it will do him good to go back to the illustration and try it out himself.

How to Approach the Question Bank

To gain the most, I would suggest the following sequence:

- **Step 1:** First, go through the text of a section thoroughly with the help of a qualified teacher. Try solving the illustrations yourself and feel the joy of discovering physics.
- **Step 2:** Then go through the multiple choice questions and the subjective exercises pertaining to that section.
- **Step 3:** At the end of that, when you are confident of the basic concepts of the entire chapter, there are additional problems given at the end of problems section.
- **Step 4:** After doing all these, you should go to the **Assertion and Reasons** (Reasoning Type Questions) section and solve them to see if you do understand the principles completely.

These problems take you to the realm of IIT JEE, Physics Olympiad, and even beyond. Do not feel discouraged if you have not been able to solve the problems at the first go. Remember, even Einstein and Newton had faced failures in their lives. Failure is a stepping stone to success. I wish you all the best in your endeavors.

My team and I have tried our level best to offer you an error-free book, even going through the whole manuscript three or four times. All the questions that have been set in the problem section has been solved twice, once by me personally and then by my colleague. Yet, it may be possible that errors may remain in the book. Comments or suggestions on the content and presentation of the book will be received with great interest and highly appreciated.

Manish Kumar Singhal
Email: mks@bansaliitjee.com

Acknowledgments

I have dedicated this book to my loving teacher Prof. P.V. Krishnan and his wife, mother Krishangi Devi. Truly, if they did not give me a spiritual vision of life, I would never even have the boldness of taking up teaching as a profession, much less to venture writing this book. He taught me the real meaning of Science and opened my eyes to a Science which is much more profound and vast than what we are studying here. I encourage all my readers to study his books, "Science and Nescience" and "Wake up! Intellectuals." They gave me an entirely new perspective to life, they will surely change yours.

This book was made possible only by an extensive help rendered by a big group of friends. The leader among them was my friend and colleague Ajit Aggarwal who laboriously went through the entire book and solved each problem personally in detail. My friend Dr. G. Partheepan at IIT Delhi was extremely prompt with his valuable help with the research papers. I am indeed very grateful to Mr. Jearl Walker for allowing me to edit the book the way I wanted. Thanks!

Thanks are also due to Amit Gupta, author of Vol. I, who introduced me to the idea. Prominent among those who helped me with the books are Kishore Rane of Paravyoma classes, Vishakhapatnam; Anurag Mishra, Bansal Classes, Kota; and Ambarish Srivastava, FIITJEE, Delhi. The kind of open heartedness which these three individuals showed in sharing their collection of books with me is a rare example in this age of hypocrisy and cynicism.

I am also deeply indebted to Mr. V.K. Bansal of Bansal classes, Kota, who gave us such an open learning atmosphere at Kota. His dedication to teaching excellence is something which is unparalleled and would be hard to beat in years to come. My editor Meenakshi Sehrawat and her entire team deserve a gold medal for keeping up with my vision of giving the students gem of a book. My typist Prashant Gupta deserves a special applause for making figures that match the quality of the original book. Special thanks are due to my students of today and past whose thought-provoking questions helped me to explore Physics deeper and deeper. Last but not the least, I owe a special thanks to Paras Bansal and Vikas Gupta at Wiley India for putting so much faith in me and risking a big investment for bringing out their first ever textbook in India in color. And that too at Indian prices! This project would have never been successful without these people supporting me.

Manish Kumar Singhal
April 2010

Note to the Student

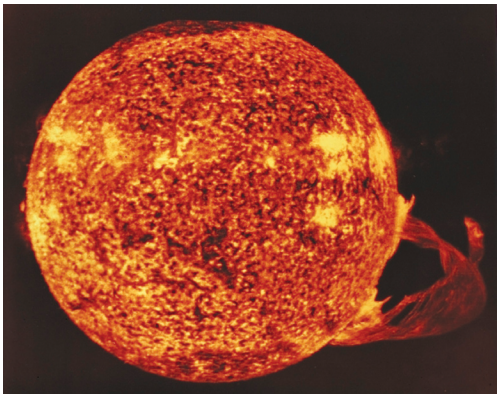
The IIT-JEE is one of the hardest exams to crack for students. For a very simple reason – concepts cannot be learned by rote, they have to be absorbed, and IIT believes in strong concepts. Each question in the IIT-JEE entrance exam is meant to push the analytical ability of the student to its limit. That is why the questions are called brainteasers!

This is where Halliday, Resnick and Walker's *Fundamentals of Physics* comes in. This text has been the definitive text for learning Physics concepts and solving problems conceptually for the last 33 years. Its unparalleled approach to teaching physics has been appreciated globally by students and teachers alike. And that is why it is probably the best resource for an IIT aspirant like you today.

In collaboration with experts from IIT-JEE coaching, the original Halliday, Resnick and Walker edition has been customized to give you the tools that will help you crack the toughest entrance exam in India.

If you take full advantage of the unique features and elements of this textbook, we believe your experience will be fulfilling and enjoyable. Let's walk through some of the special book features that will help you in your efforts to crack IIT-JEE.

A. PEDAGOGY



Courtesy NASA/JSC

At 2:45 A.M. on March 13, 1989, the entire power-grid system for the Canadian province of Quebec failed, leaving millions of people without power on that cold night. In fact, many power-grid systems in the Northern Hemisphere malfunctioned that night, creating a nightmare situation for the engineers who maintained the systems. The cause was not a sudden overtaxing demand for power or a failure of aging equipment. Rather, the cause was an explosion that had occurred on the Sun's surface three days earlier.

How can a solar explosion shut down a power-grid system?

The answer is in this chapter.

OPENING TEASER

The **opening teaser** and the related image at the beginning are meant to serve two purposes: First, they are real-life phenomena and thus make the concept something real and not just a bookish detail. And second, they make the student curious and incite him/her to get deeper into the chapter and its contents.

CONCEPT EXPLANATION

The **concept explanation** follows. This will lead you to the answer of the teaser in the beginning. The inimitable style of Halliday, Resnick and Walker is obvious in the simple language and real-life examples.

24-1 WHAT IS PHYSICS?

One goal of physics is to identify basic forces in our world, such as the electric force we discussed in Chapter 22. A related goal is to determine whether a force is conservative—that is, whether a potential energy can be associated with it. The motivation for associating a potential energy with a force is that we can then apply the principle of the conservation of mechanical energy to closed systems involving the force. This extremely powerful principle allows us to calculate the results of experiments for which force calculations alone would be very difficult. Experimentally, physicists and engineers discovered that the electrostatic force is conservative and thus has an associated electric potential energy. In this chapter we first define this type of potential energy and then put it to use.

24-2 | Electric Potential Energy

Any charge in an electric field experiences the action of a force. Consequently, a certain work is done when a charge moves in the field. This work depends on the field strength at different points and on the charge displacement. However, *if a charge describes a closed curve, that is, returns to the original position, the work done by the field is equal to zero* irrespective of the field configuration and the shape of the path along which the charge has moved.

Electric potential is a scalar property associated with an electric field, regardless of whether a charged object has been placed in that field; it is measured in joules per coulomb, or volts.

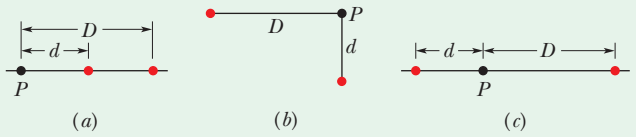
IMPORTANT POINTS

Throughout the book, important tips will be given in a box marked with a **pointed finger**. This technique highlights the tips and also aids retention.

CHECKPOINTS

These are important points after each section in the chapter that help check your understanding of what has been covered till then.

CHECKPOINT 4 The figure here shows three arrangements of two protons. Rank the arrangements according to the net electric potential produced at point P by the protons, greatest first.



PROBLEM-SOLVING TACTICS

Tactic 1: *The Symbol V and Potential Difference* In previous chapters, the symbol V represents an electric potential at a point or along an equipotential surface. However, in matters concerning electrical devices, V often represents a *potential difference* between two points or two equipotential surfaces. Equation 26-1 is an example of this second use of the symbol. In Section 26-3, you will see a mixture of the two meanings of V. There and in later chapters, you need to be alert as to the intent of this symbol.

You will also be seeing, in this book and elsewhere, a variety of phrases regarding potential difference. A potential difference or a "potential" or a "voltage" may be *applied* to a device, or it may be *across* a device. A capacitor can be charged to a potential difference, as in "a capacitor is charged to 12 V." Also, a battery can be characterized by the potential difference across it, as in "a 12 V battery." Always keep in mind what is meant by such phrases: There is a potential difference between two points, such as two points in a circuit or at the terminals of a device such as a battery.

PROBLEM-SOLVING TACTICS

These contain helpful instructions to guide the beginning physics student as to how to solve problems and avoid common errors.

B. THE 4Cs CONCEPT

It is normal to be nervous about solving tough IIT-JEE problems. But not if you know how to solve them using the 4Cs. The 4Cs is a unique and logical technique of solving problems conceptually. It is a step-based approach intended to simplify the process of applying formulas and concepts in the computation of the solution. See the Halliday way of 4Cs for solving the problem with explanations provided for each step. The purpose of each C is explained below.

CONCEPTUALIZE
First, the concept used in the problem is identified and a brief explanation of the problem is given.

CLASSIFY
Based on what value needs to be obtained and what values are given in the question, the formulae used are listed.

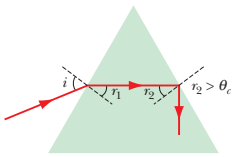
COMPUTE
The actual solution comes next, including the application of formulae and the resultant equations.

CONCLUDE
The problem ends with the explanation of the values derived as the answer.

Sample Problem 35-26

What is the relationship between A and n, so that no rays come out of second face (Fig. 35-58)?

FIG. 35-58 The prism has such a refractive index and an angle of prism combination that all the incident rays undergo total internal reflection.



Conceptualize: Here, we want to choose the refractive index of the prism such that a ray will always undergo total internal reflection. Note that this total internal reflection can occur only when the light ray goes from denser to rarer medium. In other words, this will occur only when the ray is incident on the second surface.

The situation implies that for the smallest angle r_2 also, the total internal reflection should occur.

Classify: $r_1 + r_2 = A$. So when r_2 is minimum, r_1 is maximum. The angle of incidence i is also maximum by Snell's law. But the maximum angle of incidence can be 90°. This problem implies that if a total internal reflection occurs when angle of incidence is 90°, then total internal reflection will occur at all the angles.

Compute: Applying Snell's law at the first surface:

$$1 \times \sin 90° = n \sin r_1$$
$$r_1 = \sin^{-1}\left(\frac{1}{n}\right)$$
$$r_2 = A - \sin^{-1}\left(\frac{1}{n}\right).$$

But for total internal reflection at the second surface:

$$r_2 > \theta_c$$
$$\sin r_2 > 1 \sin \theta_c\left(\frac{1}{n}\right)$$
$$A - \sin^{-1}\left(\frac{1}{n}\right) > \sin^{-1}\left(\frac{1}{n}\right).$$

Thus, the condition becomes

$$n > \operatorname{cosec}\left(\frac{A}{2}\right).$$

Conclude: Many optical instruments, such as binoculars, periscopes, and telescopes, use glass prisms and total internal reflection to turn a beam of light through 90° or 180°.

C. ASSESSMENT – AS PER IIT-JEE PATTERN

Mere theory is not enough. It is also important to test what has been taught. For the test to be effective, the assessment technique should be comprehensive. In the context of this book, the assessment also needs to be in resonance with the IIT-JEE paper pattern because unless the student practices the IIT-JEE way, he/she will not be sufficiently equipped to crack the exam. Keeping this in mind, the assessment has been divided into three main parts – *Reasoning Type Questions, Multiple Choice Questions, and Problems* – plus a section of *Additional Problems* for students interested in testing their understanding of the whole chapter. Each part contributes to the preparation of IIT-JEE because each part is modeled on the actual IIT-JEE paper.

REASONING TYPE

The first section of the assessment is reasoning-type questions, similar to the ones asked in the IIT-JEE paper. Practicing these would mean effective preparation for the exam.

REASONING TYPE QUESTIONS

In the following set of questions, a statement 1 is given and a corresponding statement 2 is given just below it. Mark the correct answer as:

(a) If both Statement 1 and Statement 2 are true and Statement 2 is the correct explanation of Statement 1.
(b) If both Statement 1 and Statement 2 are true but Statement 2 is not the correct explanation of Statement 1.
(c) If Statement 1 is true but Statement 2 is false.
(d) If Statement 1 is false but Statement 2 is true.

1. Statement 1: It is less dangerous to touch a faulty electrical appliance at 200 V than a Van de Graff generator at 20 000 V.

Statement 2: If we have two similar bodies at the different potential, the body with a higher potential will have more charge on it.

Statement 2: x component of electric field is given by

$$E_x = -\frac{\partial V}{\partial x},$$

and on equipotential surface potential V is constant.

4. Statement 1: If the distance between two point charges increases, their potential energy decreases.

Statement 2: The potential energy of two point charges is inversely proportional to the distance between the two charges.

5. Statement 1: If the electric potential at all the points in space is zero, the electric field at all the points in space must be zero.

Statement 2: If the electric field at all the points in space is zero, the electric potential at all the points in space must be zero.

MULTIPLE CHOICE QUESTIONS

sec. 24-2 Electric Potential Energy

1. A point charge Q is moved along a circular path around another fixed point charge. The work done by the electric field for one complete circle is zero

(a) If fixed charge is at the center of the circular path
(b) If the two charges have the same magnitude
(c) If the two charges have the same magnitude and opposite signs
(d) All above cases

2. Three charged particles are initially in a position 1. They are free to move and they come to another position 2 after some time. Let U_1 and U_2 be the electrostatic potential energies in position 1 and 2. Then

(a) $U_1 > U_2$
(b) $U_2 > U_1$
(c) $U_1 = U_2$

3. When a negative charge moves in a direction opposite to the direction of an electric field,

(a) The field does work on the charge
(b) The charge does work on the field
(c) The charge gains potential energy
(d) The charge loses potential energy

4. A point charge q moves from point P to point S along the path P, Q, R, and S in a uniform electric field pointing parallel to the positive direction of the x axis. The coordinates of the points P, Q, R, and S are $(a, b, 0)$, $(2a, 0, 0)$, $(a, -b, 0)$, and $(0, 0, 0)$, respectively (Fig. 24-37). The work done by the field in the above proc-

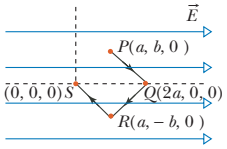


FIG. 24-37 Multiple choice question 4.

MULTIPLE CHOICE QUESTIONS

This form of Assessment forms the basis of the IIT-JEE paper. If a student becomes adept at attempting these types of questions, he/she has a good chance of doing well in the exam.

PROBLEMS

A number of numerical problems testing different concepts covered within the chapter are given here. All problems are of different levels of difficulty and meant to help students apply the concepts. Sections are mentioned for students to know which section to refer to in case of doubt.

PROBLEMS

sec. 24-2 Electric Potential Energy

1. Electrostatic work w is done on a charged particle, going from point A to point B, without any other external force acting on it. You next apply a force to move the particle back to point A, increasing its kinetic energy by an amount equal to $2w$. How much work did you do?

2. How much work is required to set up the arrangement of Fig. 24-48 if $q = 2.0\ \mu C$, $a = 9.0$ cm, and the particles are initially infinitely far apart and at rest?

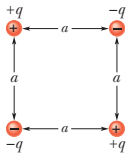


FIG. 24-48 Problem 2.

3. A particle of charge $+7.5\ \mu C$ is released from rest at the point $x = 60$ cm on an x axis. The particle begins to move due to the presence of a charge Q that remains fixed at the origin. What is the kinetic energy of the particle at the instant it has moved 40 cm if $Q = +20\ \mu C$?

4. Two charged objects are held a distance r apart. The first object has a mass m and a charge $+2q$, while the second object has a mass $2m$ and a charge $+q$. The objects are released from rest. Assume that the only force acting on either charge is the electrostatic force from the other charge. (a) When the objects are in motion what is the ratio of the first object's kinetic energy to that of the second object? What is the speed of (b) the first object and (c) the second object when they are at a large disctance from each other?

5. Two electrons are fixed 2.0 cm apart. Another electron is shot from infinity and stops midway between the two. What is its initial speed?

undergoes a change in electric potential of 12 V, how much energy is involved?

7. A positron (charge $+e$, mass equal to the electron mass) is moving at 1.0×10^7 m/s in the positive direction of an x axis when, at $x = 0$, it encounters an electric field directed along the x axis. The electric potential V associated with the field is given in Fig. 24-49. The scale of the vertical axis is set by $V_s = 500.0$ V. (a) Does the positron emerge from the field at $x = 0$ (which means its motion is reversed) or at $x = 0.50$ m (which means its motion is not reversed)? (b) What is its speed when it emerges?

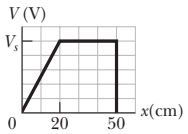


FIG. 24-49 Problem 7.

sec. 24-5 Calculating the Potential from the Field

8. When an electron moves from A to B along an electric field line in Fig. 24-50, the electric field does 3.84×10^{-19} J of

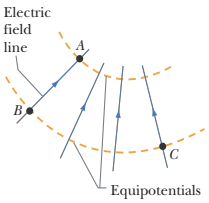


FIG. 24-50 Problem 8.

ADDITIONAL PROBLEMS

Some bonus extra problems are given as part of Assessment at the end of each chapter. These problems are not ordered or sorted in any way so that a studentmust determine which parts of the chapter apply to any given problem.

ADDITIONAL PROBLEMS

41. A nonconducting sphere has radius $R = 2.31$ cm and uniformly distributed charge $q = +3.50$ fC. Take the electric potential at the sphere's center to be $V_0 = 0$. What is V at radial distance (a) $r = 1.45$ cm and (b) $r = R$.

42. Two charged particles are shown in Fig. 24-64*a*. Particle 1, with charge q_1, is fixed in place at distance d. Particle 2, with charge q_2, can be moved along the x axis. Figure 24-64*b* gives the net electric potential V at the origin due to the two particles as a function of the x coordinate of particle 2. The scale of the x axis is set by $x_s = 16.0$ cm. The plot has an asymptote of

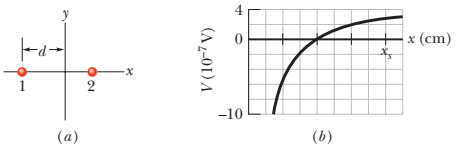


FIG. 24-64 Problem 42.

$V = 5.76 \times 10^{-7}$ V as $x \to \infty$. What is q_2 in terms of e?

43. A nonuniform linear charge distribution given by $\lambda = bx$, where b is a constant, is located along an x axis from $x = 0$ to $x = 0.20$ m. If $b = 20$ nC/m^2 and $V = 0$ at infinity, what is the electric potential at (a) the origin and (b) the point $y = 0.15$ m on the y axis?

44. *Proton in a well.* Figure 24-65 shows electric potential V along an x axis. The scale of the vertical axis is set by $V_s = 10.0$ V. A proton is to be released at $x = 3.5$ cm with initial kinetic

45. The smiling face of Fig. 24-66 consists of three items:

(a) a thin rod of charge $-3.0\ \mu C$ that forms a full circle of radius 6.0 cm;

(b) a second thin rod of charge $2.0\ \mu C$ that forms a circular arc of radius 4.0 cm, subtending an angle of 90° about the center of the full circle;

(c) an electric dipole with a dipole moment that is perpendicular to a radial line and has magnitude 1.28×10^{-21} C · m.

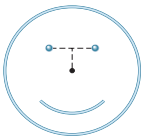


FIG. 24-66
Problem 45.

What is the net electric potential at the center?

46. In Fig. 24-67, we move a particle of charge $+2e$ from infinity to the x axis. How much work do we do? Distance D is 4.00 m.

47. A particle of positive charge Q is fixed at point P. A second particle of mass m and negative charge $-q$ moves at constant speed in a circle of radius r_1, centered at P. Derive an expression for the work W that must be done by an external agent on the second particle to increase the radius of the circle of motion to r_2.

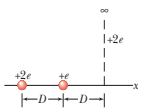


FIG. 24-67
Problem 46.

ANSWERS

The Answer key at the end of each chapter contains answers to all questions including checkpoints, reasoning questions, multiple choice questions, problems and additional problems.

ANSWERS

Checkpoints

1. a
2. (a) $11h/6$ from fish itself; (b) $17\ h/6$
3. The straw is not a ray! Note that the straw has a lateral shift as well as a bend. Actually, the rays from the straw reach our eyes after refraction from the water and the apparent depth of different parts of the straw is different from its actual value. So the straw appears to be bent.
4. $d_a = \dfrac{d\cos^3\theta}{n\cos^3\phi}$
5. (a) e; (b) virtual, same
7. Virtual, same as object, diverging

Reasoning Type Questions

1. (a)
2. (a)
3. (d)
4. (d)
5. (a)
6. (a)
7. (b)
8. (c)
9. (b)
10. (b)

Multiple Choice Questions

1. (d)
2. (b)
3. (c)
4. (a)
5. (c)
6. (b)
7. (c), (d)
8. (a)
9. (b)
10. (a)
11. (b)
12. (c)
13. (c)
14. (d)
15. (d)
16. (b)
17. (c)
18. (b)
19. (c)
20. (a)
21. (b)
22. (d)

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The topics covered in the first volume are:

- General Physics
- Mechanics
- Thermal Physics

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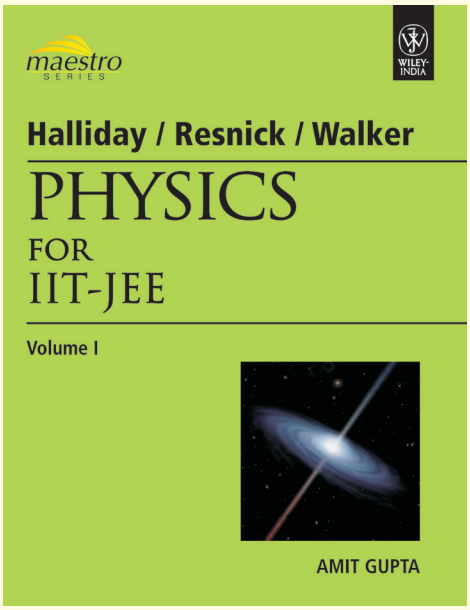

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