ESE 2025

UPSC ENGINEERING SERVICES EXAMINATION

Preliminary Examination

General Studies and Engineering Aptitude

General Principles of Design, Drawing and Importance of Safety

Comprehensive Theory *with* Practice Questions *and* ESE Solved Questions

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ESE 2025 Preliminary Examination :
General Principles of Design, Drawing and Importance of Safety

1st Edition : 2016
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Preface

B. Singh (Ex. IES)

The compilation of this book **General Principles of Design, Drawing and Importance of Safety** was motivated by the desire to provide a concise book which can benefit students to understand the concepts of this specific topic of General Studies and Engineering Aptitude section.

This textbook provides all the requirements of the students, i.e. comprehensive coverage of theory, fundamental concepts and objective type questions articulated in a lucid language. The concise presentation will help the readers grasp the theory of this subject with clarity and apply them with ease to solve objective questions quickly. This book not only covers the syllabus of ESE in a holistic manner but is also useful for many other competitive examinations. All the topics are given the emphasis they deserve so that mere reading of the book clarifies all the concepts.

We have put in our sincere efforts to present detailed theory and MCQs without compromising the accuracy of answers. For the interest of the readers, some notes, do you know and interesting facts are given in the comprehensive manner. At the end of each chapter, sets of practice question are given with their keys, that will allow the readers to evaluate their understanding of the topics and sharpen their question solving skills.

Our team has made their best efforts to remove all possible errors of any kind. Nonetheless, we would highly appreciate and acknowledge if you find and share with us any printing and conceptual errors.

It is impossible to thank all the individuals who helped us, but we would like to sincerely thank all the authors, editors and reviewers for putting in their efforts to publish this book.

With Best Wishes

B. Singh

CMD, MADE EASY

General Principles of Design, Drawing and Importance of Safety

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■■■■

1 Engineering Design Process

1.1 INTRODUCTION

What is Engineering?

According to The American Engineers' Council for Professional Development, engineering is defined as:

"The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behavior under specific operating conditions; all as respects an intended function, economics of operation or safety to life and property."

So basically engineering deals with building something or improving the design of something that already exists. The discipline of engineering is extremely broad, and contains a range of more specialized fields of engineering, each with a more specific focus on particular areas of applied science, technology and application types.

What Engineers Do?

- Engineers apply the principles of science and mathematics to develop economical solutions to technical problems. Their work is the link between scientific discoveries and the commercial applications that meet the needs of consumer as well as society as a whole.
- Many engineers develop new products. During this process, they consider several factors. For example, in developing an industrial robot, engineers precisely specify the functional requirements; design and test the robot's components; integrate the components to produce the final design; and evaluate the design's overall effectiveness, cost, reliability, and safety. This process applies to the development of many different products, such as chemicals, computers, power plants, helicopters, and toys.
- This process of solving a design problem includes creating a new product or developing an existing product for better functioning. This process is called 'The Engineering Process' or 'The Engineering Design'. This process includes a methodical series of steps that all kinds of engineers use in creating functional products and processes.

1.2 ENGINEERING DESIGN PROCESS

The engineering design process can be used to achieve several different outcomes such as:

- Designing of products, whether they be consumer goods such as refrigerators, power tools, or DVD players.
- Designing of highly complex products such as a missile system or a jet transport plane.
- Designing of a complex engineered system such as an electrical power generating station or a petrochemical plant.

The emphasis of this course is a product design because it is an area in which many engineers will apply their design skills.

1.2.1 Importance of the Engineering Design Process

Goods or services are basis for an organization's existence. A company's growth and survival depends on the profits earned by the company through its products and services. In a highly competitive market, engineering design process becomes very important owing to following factors:

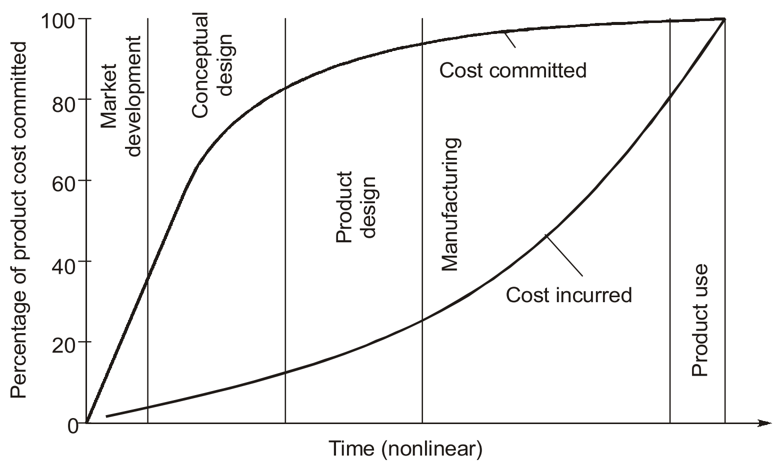

Fig. 1.1 Product cost commitment during phases of the design process

- Only a small fraction of the cost to produce a product (approximately 5%) is involved with the design process, while the remaining 95% of cost is consumed by the materials, capital and labour to manufacture the product. If the design proves to be faulty just before the product goes to market, it will cost a great deal of money to correct the problem.
- One of the aspect of quality is to incorporate within the product, the performance by the customer that are truly derived by the customer who purchases the product. The old concept of product quality was that it is achieved by inspecting the product as it come of the production line. Today we realize that true quality is designed into the product.
- Another important area where engineering design determines product competitiveness is product cycle time. Cycle time refers to the development time required to bring a new product to market. Not only does the reduced cycle time increase the marketability of a product, but it reduces the cost of product developments. Furthermore, the longer a product is available for sale, the more sales and profits there will be.

1.2.2 Types of Designs

Engineering design can be undertaken for many different reasons, and it may take different forms.

- **Original design or innovative design:** This form of design is at the top of the hierarchy. A truly original design involves invention. Successful original design's occur rarely, but when they occur, they disrupt and overtake existing markets.
- **Adaptive design:** This form of design occurs when a known solution is applied to satisfy a different need and a completely new application is produced.
- **Redesign:** This type of design is employed much more frequently. In this, engineering design is employed to improve an existing design. It is obtain accomplished without any change in the working principle or concept of original design.
- **Selection design:** Most designs employ standard components such as bearings, small motors or pumps that are supplied by vendors specialization in their manufacture and sale. Therefore, in this

case the design task consists of selecting the components with the needed performance, quality, and cost from the catalogs of potential vendors.

- **Industrial design:** This form of design deals with improving the appeal of a product to the human senses, especially its visual appeal. While this type of design is more artistic than engineering, it is a vital aspect of many kinds of design.

1.3 DESIGN METHOD VERSUS SCIENTIFIC METHOD

While scientists study how nature works, engineers create new things, such as products, websites, environments, and experiences. As engineers and scientists have different objectives, they follow different processes in their work. Scientists perform experiments using scientific method; whereas, engineers follow the creativity based engineering design process.

Science is concerned with creating knowledge about naturally occurring phenomena and objects, while design is concerned with creating knowledge about phenomena and objects of artificial. Artificial objects are those made by humans (or by art) rather than nature.

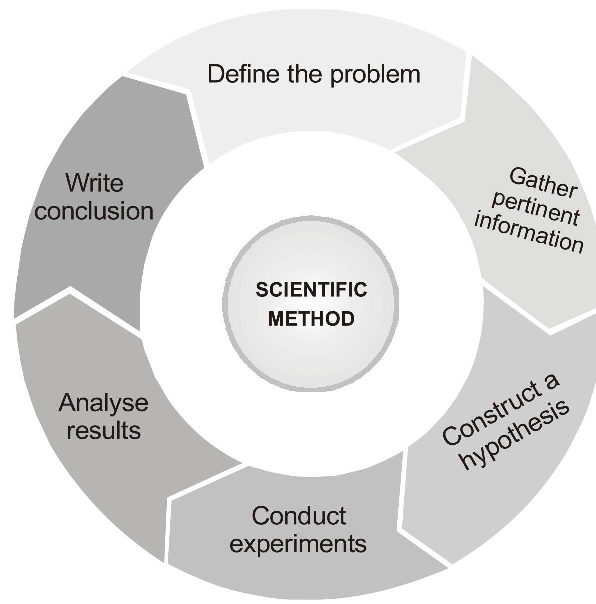

Fig. 1.2 Steps in Scientific method

1.4 STEPS IN ENGINEERING DESIGN PROCESS

The Steps Used for Solving Design Problems are:

1. Define the Problem
2. Gather Pertinent Information
3. Generate Multiple Solutions
4. Analyze and Select a Solution
5. Test and Implement the Solution

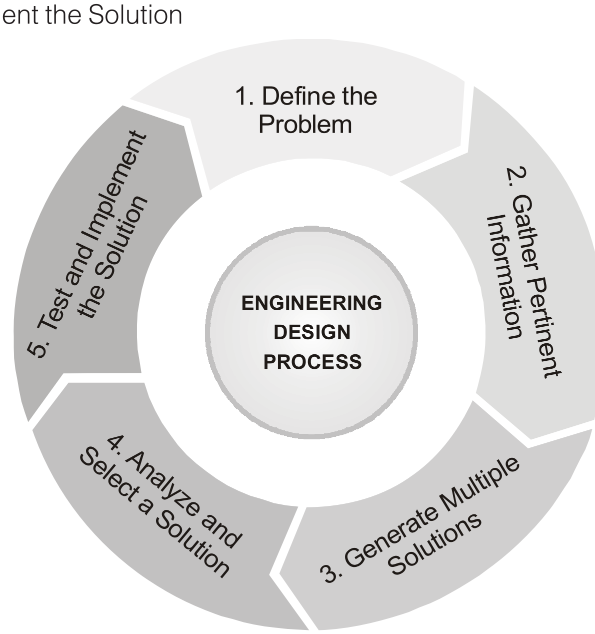

Fig. 1.3 Steps in Engineering Design Process

1.5 DESCRIPTION OF DESIGN PROCESS

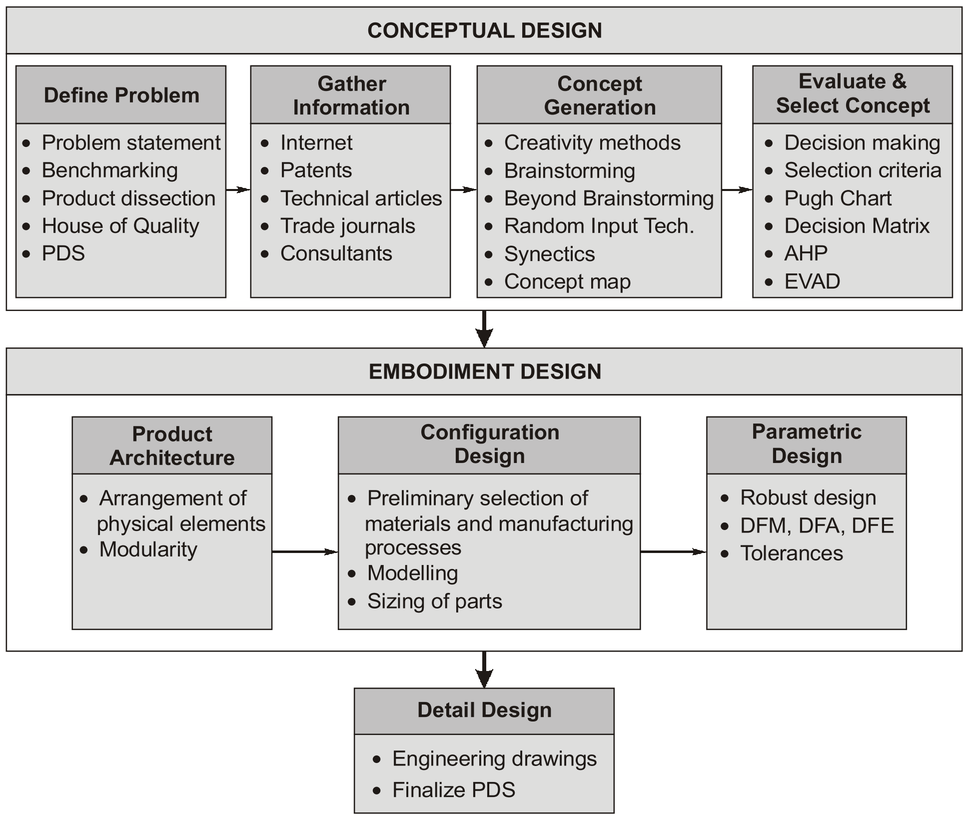

Fig. 1.4 The design activities that make up the first three phases of the engineering design process

The steps mentioned in previous article can be broken down further to what we call as description of design process or morphology of design. Figure given above shows the various activities that make up the first three phases of design: conceptual design, embodiment design, and detail design. This eight step set of design activities is representation of the basic design process.

1.5.1 Phase-I: Conceptual Design

Conceptual Design is an umbrella term given to all forms of non-aesthetic design management disciplines. It is an early phase of the design process, in which the broad outlines of function and forms are articulated. It includes the design of interactions, experiences, processes and strategies. It involves an understanding of people's needs – and how to meet them with products, services, and processes. Common artifacts of conceptual design are concept sketches and models.

The following are the discrete acitivities that we consider under conceptual design:

- Identification of customer needs: The goal of this activity is to completely understand the customers' needs and to communicate them to the design team.
- Problem definition: The goal of this activity is to create a statement that describes what has to be accomplished to satisfy the needs of the customer. This involves analysis of competitive products, the establishment of target specifications, and the listing of constraints and trade-offs. Quality Function Deployment (QFD) is a valuable tool for linking customer needs with design requirements. A detailed listing of the product requirements is called a product design specification (PDS).
- Gathering information: Engineering design presents special requirements over engineering research in the need to acquire a broad spectrum of information.

- **Conceptualization:** Concept generation involves creating a broad set of concepts that potentially satisfy the problem statement. Team-based creativity methods, combined with efficient information gathering are the key activities.
- **Concept selection:** Evaluation of the design concepts, modifying and evolving into a single preferred concept, are the activities in this step. The process usually requires several interaction.
- **Refinement of the PDS:** The product design specification is revisited after the concept has been selected. The design team must commit to achieving certain critical values of design parameters, usually called critical-to-quality (CTQ) parameters and to living with trade-offs between cost and performance.
- **Design review:** Before committing funds to move to the next design phase, a design review will be held. The design review will assure that the design is physically realizable and that it is economically worthwhile. It will also look at a detailed product-development schedule. This is needed to devise a strategy to minimize product cycle time and to identify the resources in people, equipment, and money needed to complete the project.

1.5.2 Phase-II: Embodiment Design

The embodiment process is the bridge between the conceptual stage of the design process and the detail design stage. A more detailed analysis of the selected concepts is undertaken in the embodiment stage of the design process. Subjects covered include a definitive layout, preliminary form design (component shapes and materials), preliminary production information (design for manufacture and assembly), materials and process selection and industrial design. However, the main aim is to establish concept development to refine concept sketches as a distinct stage in the design process by identifying the steps and rules employed. The input to the embodiment stage is often little more than an outline sketch and associated project controlling documentation such as PDS or design requirements. The output is a definitive scheme drawing accompanied by documentation, such as calculations, required dimension and tolerances and suggested materials and manufacturing processes. It also includes appearance, shape, style and size. Materials and process details are not included in this stage. Embodiment design is not solely the achieving of technical solutions but also creating useful products, which satisfy and appeal to the users. This design phase is sometimes called as preliminary design. Embodiment design is concerned with three major tasks - product architecture, configuration design, and parametric design.

- **Product architecture:** Product architecture is concerned with dividing the overall design system into subsystems or modules. In this step we decide how the physical components of the design are to be arranged and combined to carry out the functional duties of the design.
- **Configuration design of parts and components:** Parts are made up of features like holes, ribs, splines, and curves. Configuring a part means to determine what features will be present and how those features are to be arranged in space relative to each other. While modelling and simulation may be performed in this stage to check out function and spatial constraints, only approximate sizes are determined to assure that the part satisfies the PDS. Also, more specificity about materials and manufacturing is given here. The generation of a physical model of the part with rapid prototyping processes may be appropriate.
- **Parametric design of parts:** Parametric design starts with information on the configuration of the part and aims to establish its exact dimensions and tolerances. Final decisions on the material and manufacturing processes are also established if this has not been done previously. An important aspect of parametric design is to examine the part, assembly, and system for design robustness. *Robustness* refers to how consistently a component performs under variable conditions in its service

environment. Parametric design also deals with determining the aspects of the design that could lead to failure. Another important consideration in parametric design is to design in such a way that manufacturability is enhanced.

1.5.3 Phase-III: Detail Design

Detailed design of the system is the last design activity before implementation begins. The hardest design problems must be addressed by the detailed design or the design is not complete. The detailed design is still an abstraction as compared to source code, but should be detailed enough to ensure that translation to source is a precise mapping instead of a rough interpretation. This is the phase where the design is refined and plans, specifications and estimates are created. Detailed design will include outputs such as 2D and 3D models, cost build up estimates, procurement plans etc. This phase is where the full cost of the project is identified. In the detail design phase the following activities are completed and documents are prepared:

- Detailed engineering drawings suitable for manufacturing. Routinely these are computer-generated drawings, and they often include three-dimensional CAD models.
- Verification testing of prototypes is successfully completed and verification data is submitted. All critical-to-quality parameters are confirmed to be under control. Usually the building and testing of several preproduction versions of the product will be accomplished.
- Assembly drawings and assembly instructions also will be completed. The bill of materials for all assemblies will be completed.
- A detailed product specification, updated with all the changes made since the conceptual design phase, will be prepared.
- Decisions on whether to make each part internally or to buy from an external supplier will be made.
- With the preceding information, a detailed cost estimate for the product will be carried out.
- Finally, detail design concludes with a design review before the decision is made to pass the design information on the manufacturing.

1.5.4 Phase-IV: Planning for Manufacture

A great deal of detail planning must be done to provide for the production of the design. A method of manufacture must be established for each component in the system. As a usual first step, a process sheet is created; it contains a sequential list of all manufacturing operations that must be performed on the component. The information on the process sheet makes possible the estimation of in material or a basic change in the design. Close interaction with manufacturing, industrial, materials, and mechanical engineers is important at this step.

The other important tasks performed in phase IV are the following:

- Designing specialized tools and fixtures
- Specifying the production plant that will be used (or designing a new plant) and laying out the production lines.
- Planning the work schedules and inventory controls (production control)
- Planning the quality assurance system.
- Establishing the standard time and labor costs for each operation.
- Establishing the system of information flow necessary to control the manufacturing operation.

All of these tasks are generally considered to fall within industrial or manufacturing engineering.

1.5.5 Phase-V: Planning for Distribution

The economic success of the design often depends on the skill exercised in marketing the product. If it is a consumer product, the sales effort is concentrated on advertising in print and video media, but highly technical products may require that the marketing step be a technical activity supported by specialized sales brochures, performance test data, and technically trained sales engineers.

1.5.6 Phase-VI: Planning for Use

The use of the product by the consumer is all-important, and considerations of how the consumer will react to the product pervade all step of the design process. The following specific topics can be damnified as being important user-oriented concerns in the design process: ease of maintenance, durability, reliability, product safety, convenience in use (human factors engineering), aesthetic appeal, and economy of operation. Obviously, these consumer oriented issues must be considered in the design process at its very beginning. They are not issues to be treated as after afterthoughts.

1.5.7 Phase-VII: Planning for Retirement of Product

The final step in the design process is the disposal of the product when it has reached the end of its useful life. Useful life may be determined by actual deterioration and wear to the point at which the design can no longer function, or it may be determined by technological obsolescence, in which a competing design performs the product's functions either better or cheaper. In consumer products, it may come about through changes in fashion or taste.

1.6 SEQUENTIAL AND CONCURRENT ENGINEERING

Traditional engineering, also known as **Sequential Engineering**, is the process of marketing, engineering design, manufacturing, testing and production where each stage of the development process is carried out separately, and the next stage cannot start until the previous stage is finished. Therefore, the information flow is only in one direction and it is not until the end of the chain that occurs changes and corrections can be relayed to the start of the sequence, causing estimated costs to be under predicted.

This can cause many problems; such as time consumption due to many modifications being made as each stage does not take into account the next. This method is hardly used today, as the concept of **Concurrent Engineering** is more efficient.

Concurrent Engineering brings together multidisciplinary teams, in which product developers from different functions work together and in parallel with the intention of getting things right as quickly as possible, and as early as possible.

Sometimes, only design engineers and manufacturing engineers are involved in Concurrent Engineering. In other cases, the cross-functional teams include representatives from purchasing, marketing, production, quality assurance, the field and other functional groups. Sometimes customers and suppliers are also included in the team. In the Concurrent Engineering approach to development, input is obtained from as many functional areas as possible before the specifications are finalized.

Concurrent Engineering provides benefits such as reduced product development time, reduced design rework, reduced product development cost and improved communications.

Concurrent Engineering is greatly facilitated by the use of computer aided engineering. Concurrent engineering is a team based approach in which all aspects of the product development process are represented on a closely communicating team. Team members perform their jobs in an overlapping and concurrent manner so as to minimize the time for product development. A computer database in the form of a solid model that can be accessed by all members of the design team, Computer aided engineering became a reality when the power of the PC work station, and later the laptop PC, became great enough at an acceptable cost to free the design engineer from the limitations of the mainframe computer. Bringing the computing power of the mainframe computer to the desktop of the design engineer has created great opportunities for more creative, reliable, and cost-effective designs.

Example 1.

Consider the following steps which are used while solving the design problems:

1. Analyze and select optimum solution
2. Identify the problem and gather pertinent information
3. Test and implement the solution
4. Generate multiple solutions

What is the correct sequence of order for the design process?

(a) 2, 1, 4 and 3 (b) 1, 4, 3 and 2

(c) 2, 4, 1 and 3 (d) 1, 4, 2 and 3

[Sample Question for ESE 2017 : Released by UPSC]

Ans. (c)

Previous ESE Prelims Question

Q.1 Concurrent engineering is implemented by involving a cross-functional team for design, production, testing and operational work

(a) During the project execution (b) Long before the project execution

(c) Towards the end of the project execution (d) After completion of the project execution

[ESE 2017]

Ans. (b)

Q.2 The design of highway interchanges involves the application of the geometry of

(a) circle arcs (b) semi ellipse

(c) hyperbola (d) semi-circle

[ESE 2021]

Ans. (a)

Q.3 It is important to carefully identify the needs and expectations of the customer prior to beginning the design of mechanical device. One of the step in formulating usually quantitative statements of expected performance levels, environmental conditions in which the device must operate, limitations on space or weight, or available materials and components that may be used. These are part of which one of the following elements of design?

(a) Functions (b) Evaluation criterias

(c) Design requirements (d) Drawings

[ESE : 2024]

Ans. (c)

Objective Brain Teasers

Q.1 What is the first step in technological design process?
(a) Gathering information about an existing product
(b) Coming up with ideas for a new product.
(c) Recognizing the need for a solution to a problem
(d) None of these

Q.2 What is the last step in engineering design process?
(a) Identify a problem or need
(b) Evaluate the solution or the product
(c) Design a solution
(d) Implement the design

Q.3 When engineers develop a model, which step in the engineering process is taking place
(a) Identifying a problem or need
(b) Design a solution or product
(c) Implementing the design
(d) Evaluating the solution or product

Q.4 During which step of the design process do you test the solution or product?
(a) Identify a problem or need
(b) Design a solution or product
(c) Evaluate the solution or product
(d) Implement the design

Q.5 Which sentence describe a way scientific investigation and technological design are similar?
(a) Both start with a hypothesis
(b) Both produce a product to make life easier
(c) Both involve analyzing results of tests
(d) All of the above

Q.6 If a design flaw is discovered, what is the next logical step for the design team?
(a) Test the prototype again
(b) Scrap the project and start again
(c) Modify the design to solve the problem
(d) Obtain more money to support continued research

Q.7 ______ is the simultaneous design and development of all the processes and information needed to produce a product, to sell it, to distribute it, and to service it.
(a) Concurrent engineering
(b) Simultaneous engineering
(c) Integrated product development
(d) All of the above

Q.8 **Statement (I):** Concurrent engineering is superior to sequential engineering.
Statement (II): Concurrent engineering decreases product development time as well as cost.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true.

Answers

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

■■■■