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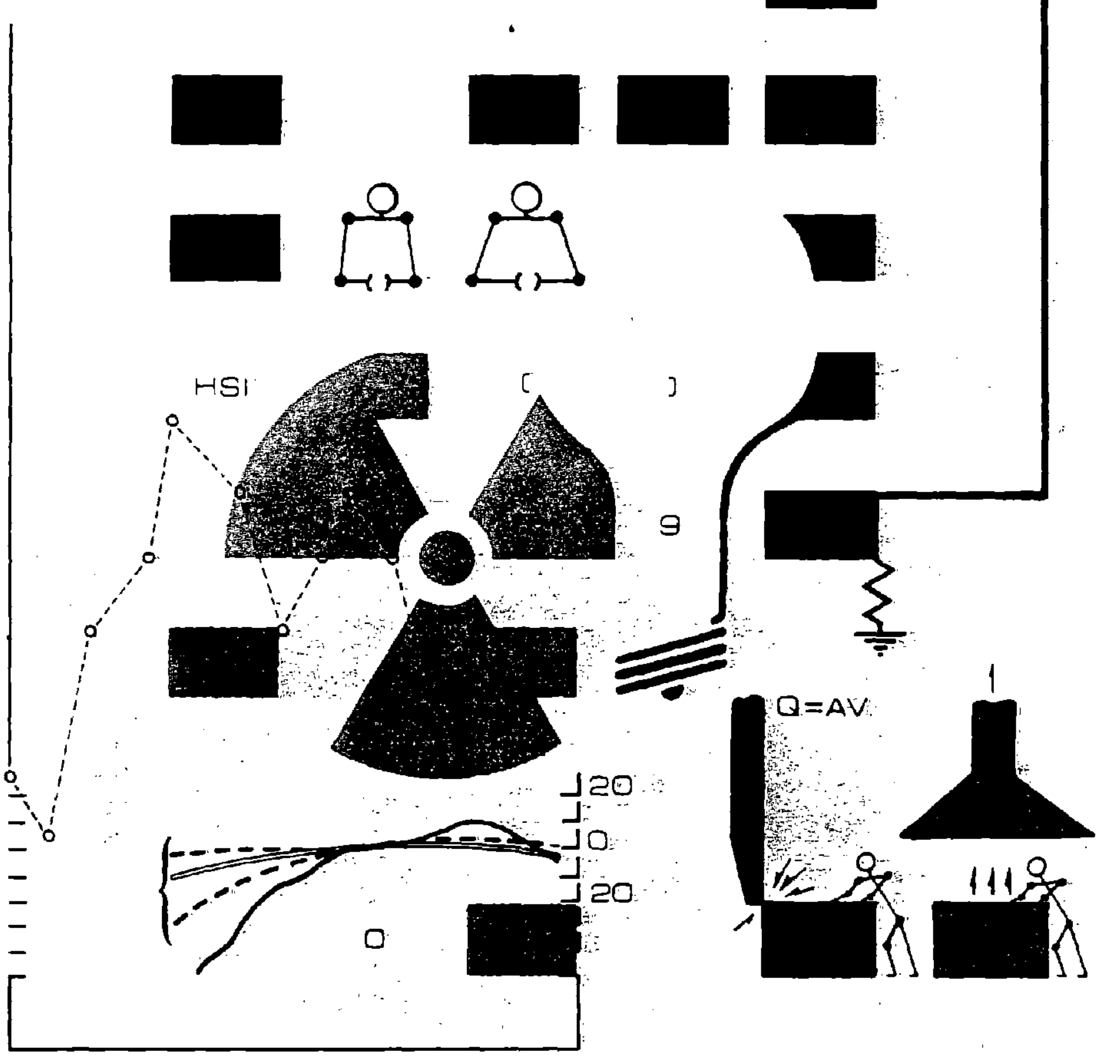
552

INDUSTRIAL HYGIENE
ENGINEERING & CONTROL

INDUSTRIAL ILLUMINATION



Instructor Manual

U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health

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16. Abstract (Limit: 200 words) The material contained in this instructor's manual was intended for use at the college level by students at an advanced level of industrial hygiene study; this module covered industrial illumination. The first lesson considered the physics of light, how light is emitted and the various sources of light. The second section discussed how light behaves after it leaves the source, the factors involved in seeing and general principles of lighting design. The third section discussed the lumen method of calculation. In the section on designing a lighting system, the manual covered quality of light; quality of light including such topics as glare, veiling reflections, brightness ratios, diffusion of light, and color; types of luminaries including indirect lighting, semi direct lighting, general diffuse or direct indirect lighting, and direct lighting. Illumination methods were also considered, including general lighting, localized general lighting, and supplementary lighting. Other factors to consider when selecting a lighting system were discussed such as choice of a light source, heat produced from the source, proper candle power distribution, efficiency of the lamp or light source, electrical features, the mechanical structure needed to support the fixture, appearance, color of lights and maintenance.

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b. Identifiers/Open-Ended Terms NIOSH-Publication, Education, Training, Industrial-hygiene, Eye-damage, Industrial-engineering, Light-source, Lighting-systems, Light-properties

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INTRODUCTION TO INDUSTRIAL HYGIENE ENGINEERING AND CONTROL (552)

This is a modularized course designed for use as a one, two, or three week short course or as a one or two semester academic course at either the undergraduate or graduate level. It examines the fundamentals for design of controls to eliminate or satisfactorily deal with occupational health hazards. Lectures, augmented by problem solving sessions, are intended to assist the trainee in selecting, designing, and applying control methods in the work environment. Primary attention is given to industrial ventilation, noise and vibration control, heat stress, and industrial illumination as well as new engineering topics.

The training course manual has been specially prepared for the trainees attending the course and should not be included in reading lists of periodicals as generally available.

Module 5 — Instructor's Manual

INDUSTRIAL ILLUMINATION

Division of Training and Manpower Development
National Institute for Occupational Safety and Health

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control

Cincinnati, Ohio

November 1978

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FOREWORD

The material presented in this document is designed for use in a college or university classroom and is directed to students at an advanced level of study in industrial hygiene. The course may also be utilized in total or in part as the basis for short course offerings.

This material was developed under sponsorship of the National Institute for Occupational Safety and Health, Division of Training and Manpower Development, Cincinnati, Ohio, (Contract CDC—210—75—0076). Serving as Project Officer for the development of this material was Robert B. Weidner, J.D., Branch Chief, Division of Training and Manpower Development.

The lesson plans and accompanying text entitled *Industrial Hygiene Engineering and Control* were prepared by the staff of Management Resource Associates, Monroeville, Pennsylvania. Serving as authors were Bruce B. Byers. Ronald J. Hritz, and James C. McClintock. Also assisting, as consultants to the development of the materials, were Ralph J. Vernon, Ph.D., and Richard B. Konzen, Ph.D., of Texas A&M University.

Art work for the text was prepared by Carole D. Byers. Manuscript preparation was the responsibility of Elaine S. Holmes.

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INTRODUCTION

Purpose of the Course

The course materials are designed for presentation to students at the baccalaureate or graduate level of study in Industrial Hygiene. The materials presuppose that the student has completed introductory courses in recognition, measurement, and evaluation of occupational health hazards. The materials are designed in such a manner that they are applicable as a two-semester course or a three-week intensive study short course. In addition, the materials may be divided to provide courses of a shorter duration. Since the course is divided into self-contained modules, each module can be used as the basis for the development of a course. (e.g., Module 2, Industrial Ventilation can be utilized as a one-semester offering or a one-week short course.)

The emphasis in each module is the control of occupational hazards. However, this emphasis does not preclude the inclusion of recognition, measurement and evaluation topics within the module. Summary material covering these important areas is included where appropriate within each module. This inclusion is based upon the authors' belief that problem identification and definition are important steps that must be taken before adequate control can be implemented.

Content

The materials are divided into eight (8) self-contained modules. Each module is divided into units and lessons. For the most part, the lessons are based upon a one-hour class session for presentation. The modules that are included, as well as the *minimum* time available to cover the modules are:

Module	*Title*	*Minimum Time*
1	Introduction to Industrial Hygiene Engineering and Control	7 Hours
2	Industrial Ventilation	31 Hours
3	Thermal Stress	4 Hours
4	Sound	7 Hours
5	Industrial Illumination	3 Hours
6	Nonionizing and Ionizing Radiation	8 Hours
7	Ergonomics	5 Hours
8	Other Topics	7 Hours
		Total Time 73 Hours

The time allotted is a minimum time that does not include allowance for testing and review of problems and exercises. Based upon the expereinces gained in a pilot test of the materials, the time allotted above provides for only a brief coverage of the topics included. For thorough coverage of each subject, the allotted time should be increased to at least 120 hours. In any case, the time required is dependent upon the level of detail and completeness of coverage of each topic that is desired.

Course Prerequisites

The students should have taken courses in recognition, measurement and evaluation of occupational health hazards. At a minimum, the students should have completed the following NIOSH sponsored courses or their equivalent:

—Recognition, Evaluation and Control of Occupational Hazards
—Industrial Hygiene Measurements

In addition, the students should have completed education in undergraduate mathematics through the calculus and undergraduate science including general and organic chemistry, physics, and biology. Additional engineering courses such as fluid mechanics and thermodynamics will be helpful to the student.

Components of the Course

The Course Manual is designed to provide the technically competent instructor with the basic educational materials from which to conduct the training sessions. It is not the purpose of the Course Manual to provide a complete skill and knowledge package from which the instructor can obtain the technical competency necessary to conduct training, since such competence is assumed to be an attribute of any instructor chosen to teach in the program. Should the instructor wish to brush up on certain skills and knowledge, the references cited as well as the accompanying text, *Industrial Hygiene Engineering and Control*, will provide a basis for this undertaking.

The course is organized with three (3) basic elements. These elements are:

1. Module—A complete, self-contained package of educational materials that is directed toward the attainment of skills and knowledge in a subject area. These modules can be presented as a stand-alone course or can be combined in various ways to construct courses for use with selected groups of students.

2. Unit—A self-contained package of educational materials that is directed toward attainment of a subset of skills and knowledge in a subject area. The unit does not necessarily lend itself to use as a stand-alone package since certain segments of the skills and knowledge presented depend upon completing previous units within the module.

3. Lesson—Generally, an artificial segmentation of a unit for administrative purposes. Lesson segments are normally one hour in length and, as far as is practical, cover a logical subset of knowledge or skills. Lessons allow for the scheduling of the training in various educational environments.

Instructor's Manual—The Module Plan

The module plan contains the following components:

1. Unit and Lesson Topic Outlines—This outline presents the topics covered within the module and the schedule for presentation of these topics. This information provides a concise and organized summary of the subject material in the module.

2. Terminal Objectives—General competency statements related to the skills and knowledge that should be possessed by the student upon completion of

the module. The skill objectives relate to the manipulative, computational, or decision-making skills that the student should attain upon completion of the module. The knowledge objectives relate to the subject knowledge that the student requires in order to perform the required skills. These objectives serve as a basis upon which an evaluation can be made of the student's mastery of the subject material included in the module.

3. Self-Tests—Postmodule self-tests along with the correct answers to these tests are included with each module.

4. References—A list of reference material can be consulted by the instructor or students.

Instructor's Manual—The Unit Plan

The unit is made up of a number of specific components and contains the lesson content outline. The components of the unit plan are:

1. Performance Objectives—Skill and knowledge objectives related to the subject matter included within the unit. These objectives are written in behavioral terms (i.e., an observable activity or result that can be evaluated quantitatively, as specified, and which is conducted or obtained under specific conditions). The objectives that are presented within the unit plan are of a more specific nature than those terminal objectives or competency statements that are specified by the module plan. The performance objectives presented within the unit might be thought of as enabling objectives; i,e., they represent the skills and knowledge that the student must attain in order to complete the requirements of the terminal objectives for the module.

2. Unit Activities—Activities that the student must perform to complete the unit. Reading assignments, reference materials, and outside activities are presented.

3. Required Facilities, Equipment, and Materials—Materials—The required facilities, equipment and materials that should be available for presentation of the unit. The equipment and materials listed are divided into those which are educational and those which are content oriented (e.g., 16 mm projector vs. pitot tube).

4. Content Outline—Presents an organized outline of the topics to be covered during the presentation of the unit. The content outline is divided into the lesson outlines necessary for completion of the units.

   In addition, the content outline contains instructions to the instructor and reference to slides and overlays that should be used in conjunction with the lecture. These instructions present the sequence of instructor activities, such as when to present a given slide, when a demonstration is required, or when an instructor's experience might be of value.

   Since the course is designed to be taught by technically competent instructors, the material in the lesson content outline is of a topical nature with only that explanation present that should be emphasized to the student. It is expected that the instructor's skill and knowledge will allow for the depth of presentation and emphasis required. The instructor is encouraged to present material relevant to experience, wherever possible, in order to provide the students with a referent to the subject.

5. Demonstration Outlines—Appropriate outlines for classroom and laboratory demonstrations and sample problems to be presented to the class. The demonstrations are designed to present an outline of the procedural steps that are important in performing the particular measurement, design, or calculation. Steps that are critical or that may lead to common errors are emphasized in the demonstration outlines.

6. Practice Exercises—A series of practice exercises that can be given to the student. These practice exercises can be used as either classroom or laboratory exercises or as homework assignments. Solutions to problems involving calculations are also provided.

Audio Visual Aids

A set of slides, which are referenced in the lesson outlines, have been prepared and are available for use in presenting the course.

Module 5

Industrial Illumination

Instructor's Manual

Unit and Lesson Topic Outline

Industrial Illumination	Module 5

The topics listed below are included within this module. The recommended time to be allotted for each topic is also given. Depending upon the background of the class, this time may vary slightly; however, the total time for the entire module should not exceed the time given.

Unit	Lesson	TOPIC	Time/Hrs.	COMMENTS
1		Industial Illumination		
	1	Light	1	Discusses the physics of light, how light is emitted, and the various sources of light.
	2	Light and Seeing/Design of a Lighting System	1	Discusses how light behaves after it leaves the source, the factors involved in seeing, and general principles of lighting design.
	3	Lighting Design	3	Discusses the lumen method of calculation.
				Total Module Time--3 Hours

Terminal Objectives

Industrial Illumination	Module 5

The objectives presented represent the competencies which the student should possess upon completion of this module. All objectives are directed toward the student's obtaining certain category levels of skill and knowledge.

Terminal Objectives

1. Given the following equations:

   a. $$\text{Number of Lamps} = \frac{\text{Foot-candles x area}}{\text{Lumens per lamp x coefficient of utilization x light loss factor}}$$

   b. $$\text{Number of luminaires} = \frac{\text{Number of lamps}}{\text{Lamps per luminaire}}$$

   c. $$\text{Cavity ratio} = \frac{10H}{\text{Room width}} \text{ x Gaysunas Ratio}$$

   where H denotes height of cavity (room, floor, or ceiling)

   d. Light loss factor = ballast performance x transmission and luminaire reflectance x dirt depreciation x lumen depreciation

   the following charts or tables:

   a. Table of Gaysunas Ratios
   b. Effective Cavity Reflectance Table
   c. Tables of Coefficients of Utilization
   d. Curves (one for each category of luminaire) of Dirt Depreciation
   e. Tables of Lamp Data (including Lumen Depreciation Data)
   f. Recommended Levels of Illumination Table

   and the following information:

   a. dimensions of a room (length, width, height)
   b. ballast performance data of a given fixture
   c. luminaire reflectance and transmission data of a given fixture
   d. type of fixture (category) and type of lamps to be used
   e. maintenance schedule in months
   f. dirt conditions of the room (very clean, clean, medium, dirty, very dirty)
   g. type of room (warehouse, office, storage area, etc.)
   h. height of cavity (ceiling cavity only), work plane (designed to be 2 1/2 feet above floor)
   i. the reflectance of walls, ceiling, and floor

(Continued)

Terminal Objectives	
Industrial Illumination	Module 5

1. (Continued)

   the student will be able to

   a. compute the number of lamps required to meet the standards and compute the number of luminaires needed
   b. arrange the luminaires in the room; identify the number of rows, luminaires per row, and how the luminaires should be laid out (parallel or perpendicular) to the line of vision

   Note: Calculation will be corrected for the effective floor reflectance.

2. Upon request, the student will be able to list the benefits of adequate industrial illumination; the list to contain at least 5 benefits.

3. Upon request, the student will write a two-page document which explains how light is produced. The description will contain the following:

   a. definition of light
   b. definition and pictorial representation of an electromagnetic wave.
   c. definition of photon.
   d. description of the process of excitation and de-excitation of an atom.
   e. pictorial representation of how either a neon light or a fluorescent light works.

4. Upon request, the student will be able to write a paragraph that explains how and why light bends when going from one medium to another.

5. Given foot-lamberts and foot-candles, the student will be able to calculate the reflectance of a given surface.

6. Upon request, the student will be able to list the four factors in seeing. The list must contain a brief description of each factor.

Unit 1

Industrial Illumination

Performance Objectives		
Lesson	Industrial Illumination	Module 5 Unit 1
1	1. Given a list of statements, the student will be able to select the statement that best describes the purpose of lighting in the industrial environment.	
1	2. Upon request, the student will be able to list the advantages of adequate industrial lighting.	
1	3. Given a list of at least four statements, the student will be able to select the statement that describes or defines light.	
1	4. Given a list of at least four statements, the student will be able to select the statement that best describes an electrical field.	
1	5. Given a diagram of a positively charged and a negatively charged particle, the student will be able to draw lines indicating the electrical fields around each charge and lines indicating the interaction between the two charges.	
1	6. Upon request, the student will write a sentence describing how a magnetic field is produced.	
1	7. Given a list of at least four statements, the student will be able to select the statement that best defines or describes a magnetic field.	
1	8. Given a diagram indicating the moving of an electrical charge and the direction of a magnetic field, the student will be able to indicate with an arrow the direction of the force.	
1	9. Upon request, the student will be able to describe in writing how a magnetic field can induce an electrical field.	
1	10. Upon request, the student will be able to draw an electromagnetic wave.	
1	11. Given a list of statements, the student will be able to select the statement that best describes the relationship between velocity, frequency, and wavelength of light.	
1	12. Given the electromagnetic spectrum, the student will indicate where visible light is along the spectrum.	
1	13. Given a list of statements, the student will select the statement that best describes what must vibrate to produce light--an electron moving to a lower level energy level.	
1	14. Given a list of statements, the student will be able to select the statement that best describes the process of excitation and de-excitation.	
1	15. Given a list of statements, the student will be able to select the statement that best describes what "particle" is emitted when an excited atom becomes de-excited.	

Lesson	Performance Objectives	
	Industrial Illumination	Module 5 Unit 1
1	16. Upon request, the student will write a description explaining how a neon light works.	
1	17. Given a list of at least four statements, the student will be able to select the statement that best describes the emission spectrum.	
1	18. Upon request, the student will be able to describe in writing how an incandescent lamp works and why it emits "white" light.	
1	19. Given a list of statements, the student will be able to select the statement that best describes the process of fluorescence.	
1	20. Given a list of statements, the student will be able to select the statement that describes why some material becomes excited when exposed to ultraviolet light.	
1	21. Upon request, the student will describe in writing how a fluorescent lamp works.	
1	22. Upon request, the student will be able to list the advantages and disadvantages of a. incandescent lamps b. mercury vapor lamps (high pressure mercury) c. fluorescent lamps	
2	23. Given a list of at least four statements, the student will be able to select the statement that best defines the term "ray of light."	
2	24. Given a list of at least four statements, the student will be able to select the statement that best describes the law of reflection.	
2	25. Given a list of surfaces, the student will be able to select the surfaces that reflect the most and the least light.	
2	26. Given a series of diagrams, the student will be able to label the diagrams according to the type of reflection they illustrate: a. specular b. diffuse c. spread d. mixed	
2	27. Given a list of at least four statements, the student will be able to select the statement that best describes transmission of light.	
2	28. Given a list of at least four statements, the student will be able to select the statement that best defines the term "refraction."	
2	29. Upon request, the student will be able to write a paragraph that explains why light is refracted.	
2	30. Given a diagram of refracted light going through an unidentified medium, the student will be able to tell if the material is denser than air.	

Performance Objectives		
Lesson	Industrial Illumination	Module 5 Unit 1
2	31. Given a list of at least four statements, the student will be able to select the statement that best describes the terms "scattering."	
2	32. Given a written description of light behavior, the student will be able to identify what behavior is being described.	
2	33. Given a diagram of superimposed light waves, the student will be able to label the areas of both constructive and destructive interference.	
2	34. Given two lists of terms, one list containing labels, the other containing units, the student will be able to match the labels with their proper units of measurement. The list, at a minimum, will contain the following labels: a. Luminous intensity b. Luminous flux c. Illumination d. Luminance e. Reflectance	
2	35. Upon request, the student will be able to write the name of the instrument to measure a. foot-candles b. luminance	
2	36. Upon request, the student will write a paragraph explaining how reflectance can be measured.	
2	37. Given a list of at least four statements, the student will be able to select the statement that best describes how brightness can be measured using a foot-candle meter.	
2	38. Upon request, the student will be able to list what information a lighting survey should contain.	
2	39. Upon request, the student will be able to list four factors involved in seeing industrial tasks.	
2	40. Given a list of at least four statements, the student will be able to select the statement that best describes the term "visual acuity."	
2	41. Upon request, the student will be able to write a paragraph explaining the relationship between the four factors.	
3	42. Upon request, the student will be able to write a sentence explaining how the recommended foot-candle levels should be interpreted.	
3	43. Given a list of sources, the student will be able to select from the list the sources of glare.	
3	44. Given a list of statements, the student will be able to select the statement that best describes how light can be controlled.	

Performance Objectives		
Lesson	Industrial Illumination	Module 5 Unit 1

3	45. Given a list of at least four statements, the student will be able to select the statement that best defines or describes veiling reflections.
3	46. Given a list of at least four statements, the student will be able to select the statement that best describes or defines the brightness ratio.
3	47. Given a list of statements, the student will be able to select the statement that best describes the best brightness ratio.
3	48. Given a list of at least four statements, the student will be able to select the statement that best describes or defines diffusion.
3	49. Given a list of at least four statements, the student will be able to select the statement that best describes how diffusion is measured.
3	50. Given a list of statements, the student will be able to select the statements that best define the following terms: a. indirect light b. semi-indirect light c. general diffuse light d. semi-direct light e. direct light f. direct-indirect light
3	51. Given a list of at least four statements, the student will be able to select the statement that best defines general lighting.
3	52. Given a list of statements, the student will be able to select the statement that best defines the term, "localized general lighting."
3	53. Given a list of at least four statements, the student will be able to select the statement that best defines supplemental lighting.
3	54. Given a list of at least four statements, the student will be able to select the statement that best describes the major concern when using supplemental lighting.
3	55. Upon request, the student will be able to list at least eight factors that must be considered when designing a lighting system.
3	56. Given a list of at least four statements, the student will be able to select the statement that best defines group relamping.
3	57. Given a list of statements, the student will be able to select the statement that best describes why maintenance of room surfaces is important for lighting.
3	58. Given a list of at least four statements, the student will be able to select the statement that best defines the term, "lumen method."

Performance Objectives		
Lesson	Industrial Illumination	Module 5 Unit 1

3 59. Given a list of at least four statements, the student will be able to select the statement that best defines the term or point-by-point procedure.

3 60. Given a list of at least four statements, the student will be able to select the statement that best defines the coefficient of utilization.

3 61. Given a set of statements, each set containing at least four statements, the student will be able to select the statements which best define or describe

a. room cavity ratio
b. ceiling cavity ratio
c. floor cavity ratio
d. effective ceiling reflectance
e. effective floor reflectance

3 62. Given a list of statements, the student will be able to select the statement that best defines the light loss factor.

3 63. Upon request, the student will be able to list at least four factors that make up the light loss factor.

3 64. Given two sets of four statements each, the student will be able to select the statements that best define

a. lamp lumen depreciation
b. luminaire depreciation

3 65. Given a description of a situation, the student will be able to properly locate the luminaires.

Unit Activities--Instructor	
Industrial Illumination	Module 5 Unit 1

In order to present the material to the student, the instructor is responsible for the following:

Lesson 1--Light

Classroom Presentation

Conduct a lecture related to:

a. Definition of light
b. Definition of electromagnetic wave
c. How electromagnetic waves and light are produced
d. Description of atom excitation and de-excitation
e. How incandescent, mercury vapor, and fluorescent lamps work

Time Allotted

1 Hour

Demonstration

No demonstrations are required

Supervised Practice

No supervised practice is required.

Lesson 2--Light and Seeing/Design of a Lighting System

Classroom Presentation

Conduct a lecture related to:

a. Law of reflection
b. Transmission of light
c. Refraction of light
d. Scattering of light
e. Diffusion of light
f. Interference
g. Units of measurement and light terminology
h. How to take a light survey
i. Factors involved in seeing industrial tasks

Time Allotted

1 Hour

Demonstration

No demonstrations are required.

Supervised Practice

No supervised practice is required.

Industrial Illumination	Module 5 Unit 1

Lesson 3--Lighting Design

Classroom Presentation

Conduct a lecture related to:

a. Quantity of light needed to perform industrial tasks
b. Quality of light needed to perform industrial tasks
c. The use of the lumen method of calculation

Time Allotted

1 Hour

Demonstration

No demonstrations are required.

Supervised Practice

No supervised practice is required.

Unit Activities--Student	
Industrial Illumination	Module 5 Unit 1

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 1--Light

Classroom Activity

Attend a lecture on the subject of the concept of light and electromagnetic waves.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control	Section 5 Chapter 1	Section 5 Chapter 1
PROBLEMS		
Self-Test	Section 4	Section 4

Unit Activities--Student

Industrial Illumination	Module 5 Unit 1

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 2--Light and Seeing/Design of a Lighting System

Classroom Activity

Attend a classroom lecture dealing with the principles of light and seeing.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control	Section 5 Chapter 2	Section 5 Chapter 2
PROBLEMS		

Unit Activities--Student	
Industrial Illumination	Module 5 Unit 1

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 3--Lighting Design

Classroom Activity

Attend a classroom lecture dealing with the factors involved in seeing and the lumen method of designing lighting systems.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control	Section 5 Chapter 3	Section 5 Chapter 3
PROBLEMS		

Equipment, Material, and Facilities	
Industrial Illumination	Module 5 Unit 1

Facilities

Lecture/discussion--Normal classroom

Equipment and Material

Educational

Chalkboard
Chalk
Eraser
35 mm Slide Projector with remote control
Screen

Health and Safety

None required

Visuals

Slide Series--Industrial Hygiene Engineering and Control, Module 5, Unit 1

References Used in Class

Industrial Hygiene Engineering and Control

Lesson Outline	
Light	Module 5 Unit 1 Lesson 1

TOPIC	REMARKS
I. Introduction A. Purpose of Industrial Lighting 1. To provide efficient and comfortable seeing of industrial tasks and to help provide a safe working environment. 2. Not safety alone. a. lighting adequate for seeing production and inspection tasks will be more than needed for safety alone b. lighting is more for comfort and convenience B. Adequate Industrial Lighting 1. Advantages. a. promotes few production and inspection mistakes b. increases production c. reduces accidents d. improves morale e. improves housekeeping	The purpose of this lesson is to familiarize the student with the concept of light and electromagnetic waves as well as the process of excitation and de-excitation of atoms.
II. Physics of Light A. What is Light? 1. Definition--Light is simply electromagnetic radiation in the range of 4.3×10^{14} Hz to 7×10^{14} Hz. 2. Light is really a wave plus more. a. light is wave-like b. light is also particle-like B. What is Electromagnetic Radiation? 1. To understand this, need to know what electrical fields and magnetic fields are.	Before discussing light in the industrial environment, the students will need to know what light is. Slide 5.1.1.1.--Definition of Light

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2. Structure of atom. a. protons (positively charged) b. electron (negatively charged) c. neutrons (neutrally charged)	Draw a picture of an atom on the chalkboard.
3. Charges. a. loss of electron makes atom positively charged b. gain of electron makes atom negatively charged c. normal case--same number of protons as electrons	
4. Electrical forces and fields. a. objects with same charge repel; object with unlike charges attract	
b. Charles de Coulomb's law	Slide 5.1.1.2.--Coulomb's Law
(1) force of attraction on repulsion is inversely proportional to square of distance (2) $F = \frac{kqq'}{r^2}$ where F denotes force, q and q' magnitude of two charges, r denotes the distance between the two charges, and k is Coulomb's constant	Coulomb's constant--a proportionality factor that takes into account the property of the medium between the two charges. Slide 5.1.1.3.--Illustration of Coulomb's Law

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TOPIC	REMARKS
c. electrical field	
(1) electrically charged bodies alter the space around them; i.e., create a field	
(2) electrical field is said to exist in a region of space in which an electrical charge will experience an electrical force	Slide 5.1.1.4.--Definition of Electrical Field
(3) strength of field (electrical field intensity) $E = \frac{F}{+q}$	Slide 5.1.1.5.--Electrical Field Intensity Formula
where E denotes electrical field intensity, F denotes force, +q denotes a positive test charge	Slide 5.1.1.6.--Direction of Electrical Field
(4) positive (outward movement); negative (inward movement)	
(5) two charged bodies and electrical field intensity if $F = \frac{kqq'}{r^2}$ then $E = \frac{F}{+q}$ $= \frac{kqq'/r^2}{+q}$ $= \frac{kq'}{r^2}$	
5. Magnetic forces and fields.	
a. law of force: like magnetic poles attract while unlike magnetic poles repel	Slide 5.1.1.7.--Law of Magnetic Force

TOPIC	REMARKS
b. de Coulomb's discovery (1) force of attraction or repulsion between two magnetic poles is inversely proportional to the square of the distance between the poles (2) force of attraction or repulsion between two poles is along a line joining the two poles and directly proportional to the product of the two pole strengths	
(3) mathematical representation $F = \frac{kp_1p_2}{r^2}$ where F denotes force, p_1 and p_2 denote pole strength of poles 1 and 2 respectively, r denotes the distance between the poles, and k denotes Coulomb's constant	Slide 5.1.1.8.--Mathematical Representation of Coulomb's Law
c. magnetic fields (1) space surrounding magnet (2) strength of magnetic field at any point referred to as magnetic field intensity (H)	
(3) $H = \frac{F}{P}$ where H denotes magnetic field intensity, F denotes force, and p denotes a north pole	Slide 5.1.1.9.--Magnetic Field Intensity Expression

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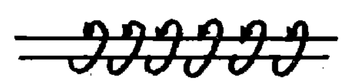
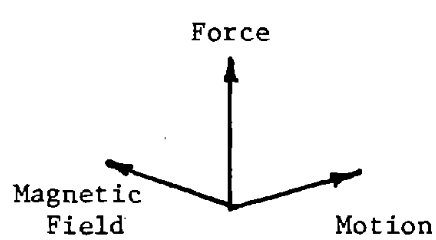
(4) $H = \frac{F}{p'} = \frac{kpp'/r^2}{p'} = \frac{kp}{r^2}$ defines the magnetic field intensity if a test pole is brought near another pole	
(5) magnetism -results from movement of electron -spin of electron about axis -orbit of electron about nucleus	Slide 5.1.1.10.--Magnetism and Movement of Electron Slide 5.1.1.11.--Illustration of Movement of Electron
6. Electric and magnetic forces a. a charged particle at rest creates an electrical field; moving charge creates a magnetic field	Slide 5.1.1.12.--Moving Charge Creates a Magnetic Field  Magnetic Field
b. a moving magnetic field will create an electrical field	Slide 5.1.1.13.--A Moving Magnetic Field
c. both of the above involve the same principle: Principle: A moving charge experiences a force that is perpendicular to the magnetic field in traverses. (1) Faraday's Law, and (2) Maxwell's Law	Slide 5.1.1.14.--Force-Motion and Magnetic Field 

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5. The production of a wave. a. consider an electrical charge vibrating back and forth at a certain frequency b. charge has an electrical force c. moving charge creates a magnetic field d. however, magnetic field is also changing and magnetic field produces an electrical field e. thus, the two fields mutually induce each other; the changing magnetic field induces an electrical field which induces a magnetic field, etc., and waves are produced (1) critical speed without loss or gain of energy is 186,000 miles per second C. Electromagnetic Spectrum 1. Electromagnetic waves travel at the same speed in a vacuum. 2. Differ from one another in frequency and wavelength. 3. $C = f\lambda$ C = velocity f = frequency λ = wavelength 4. Some wavelengths. a. AM radio--1,000 feet b. FM waves--10 feet c. visible light--35 to 75 millionths of a centimeter	

TOPIC	REMARKS
5. Electromagnetic wave spectrum a. radio waves b. microwaves c. infrared waves d. visible light e. ultraviolet f. X-rays g. gamma rays	Slide 5.1.1.15.--Electromagnetic Waves
D. Quantum Theory of Light	
1. Light is wave-like but also particle-like.	
2. Discovery of photoelectric effect called for a further definition of light.	Discuss photoelectric effect. Slide 5.1.1.16.--Photoelectric Effect An electrical spark would jump more readily between charged fields where this surface was illuminated.
a. the brightness of the light in the photo-electric effect did not affect the energies of the ejected electrons	If light was electromagnetic radiation, the stronger electrical field of brighter light would interact with electrons causing them to eject at greater speeds and thus greater energies. This does not happen.
b. thus, light needed to be investigated further	
3. Planck's Theory	
a. the problem with the electromagnetic theory was with the assumption that energy is radiated continuously	
b. he postulated that electromagnetic energy is absorbed or emitted in pockets called "quanta"	

TOPIC	REMARKS
c. the electron in an atom could vibrate only in discrete quantities d. electron in orbit further from the nucleus has a greater potential energy than one closer; thus an electron further away has a higher energy level. An electron can move in energy levels only in discrete steps	
4. Excitation and de-excitation.	Slide 5.1.1.17.--Excitation and De-excitation of Atoms
a. when an electron is in any way raised to a higher energy level, the atom is said to be excited b. electron's higher energy level is only momentary	
c. electron loses its temporarily acquired energy in returning to a lower level, and this energy is released as a photon (called de-excitation)	Point out: The photon is the particle part of light energy. Every atom or element has its own characteristic energy levels; thus the amount of energy released would be different when an electron moves to a higher level then drops to a lower level. Note: The excitation/de-excitation process can be accurately described only by quantum mechanics. An attempt to view the process in terms of classical physics runs into considerable contradiction. Classically, electromagnetic radiation is induced by an accelerating charge. Interestingly enough, an electron does accelerate in a transition from a higher to a lower energy level; the electrons in the innermost orbits of the atom have greater speeds. An electron, therefore, gains speed in dropping to lower energy levels. Fine--the (Continued)

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	accelerating electron radiates a photon. But not so fine--the electron is continually undergoing acceleration (centripetal acceleration) in any orbit, whether or not it changes energy levels. Classically, it should continually radiate energy, but it does not.
d. Planck postulated that the energy of a resulting photon of radiation would be equal to the difference in the energy states of the atom e. further, he postulated that the frequency of the emitted radiation is proportional to this energy difference $E = hf$ where E denotes energy of the photon, f denotes frequency, and h is the proportionality factor called "Planck's Constant"	
f. thus, light has both wave-like properties and particle-like properties	Thus a photon or quantum of infra-red radiation then has a tiny energy; a quantum of green light, a small energy; and a quantum of ultraviolet light, a larger energy.
5. Application of excitation and de-excitation. a. each element has its own characteristic set of energy levels and number of electrons b. each electron as it jumps to a lower level emits a photon	

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c. many frequency characteristics of the atom are emitted--each element, therefore, has its own characteristic of color	
d. neon lights	
-different colors correspond to different gases (only red is due to neon)	
-procedure	Slide 5.1.1.18.--Neon Light
Electrodes are at the end of the glass tube containing neon gas. Electrons are boiled off these electrodes and are moved back and forth at high speeds by a high AC voltage. Millions of high-speed electrons vibrate back and forth inside the glass tube and smash into millions of target atoms; each smash drives orbital electrons into higher energy levels by an amount of energy equal to the decrease in kinetic energy of bombarding electron. When the electron falls to its normal level, light (red) is seen. This is nothing more than the process of excitation and de-excitation.	
e. each atom would emit its own type of color	
E. Emission Spectrum	
1. Background information.	
a. every element has its own characteristic pattern of electron levels	

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b. therefore, it emits its own characteristic pattern of light frequencies when excited c. this unique pattern can be seen through a prism d. each component color is focused at a definite position according to its frequency	Slide 5.1.1.19.--Typical Spectral Pattern
2. Typical patterns. a. sodium produces a single yellow line b. mercury vapor -two strong yellow -intense green -and several blue and violet c. neon is at orange and red range	These lines correspond to the electron transitions between atomic energy levels.
3. Incandescences. a. neon--red because average difference in neon energy levels is proportional to the frequency of red light b. light emitted from incandescent lamp is white (all frequencies of visible radiation are emitted). <u>Does this mean that the tungsten atoms making up the lamp filament are characterized by an infinite number of energy levels?</u> -No, if the filament were vaporized and then excited, the tungsten gas would emit a finite number of frequencies producing predominantly blue light	

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	The frequency of light emitted by atoms depends not only on the energy level spacings within an atom but also on the spacings between neighboring atoms themselves. In a gas, the atoms are far apart. Electrons undergoing transitions between energy levels within the atom are unaffected by the presence of other atoms. But when the atoms are closely packed, as in a solid, electrons of the outer orbits make transition not only within the energy levels but also between levels of neighboring atoms. These energy level transitions are no longer well defined but are altered by interactions between neighboring atoms, resulting in an infinite variety of energy level differences; hence, the infinite number of radiation frequencies.
c. mercury vapor light is brighter and less expensive than incandescent lamps; most of the energy in incandescent lamps is converted to heat--most of the energy put into mercury vapor lamps is converted to light.	As the filament becomes heated, wider energy level transitions take place, and higher frequencies of radiation are emitted. A hotter filament provides a whiter white.
4. Fluorescences and fluorescent lamps. a. basic principles -atoms absorb light as well as emit light	

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-an atom will most strongly absorb light having the same frequency(ies) to which it is tuned; i.e., the same frequency it emits -e.g., when a beam of white light passes through a gas, the atoms of the gas absorb selected frequencies. The absorbed light is re-radiated but in all directions, instead of the direction of the evident light	
b. application of principles	
-some atoms become excited by absorbing a photon of light -ultraviolet light has more energy per photon than lower frequency light -many substances undergo excitation when illuminated by ultraviolet light -some substances excited by ultraviolet light emit visible light upon de-excitation; this action is called <u>fluorescences</u>	Slide 5.1.1.20.--Fluorescences As a photon of ultraviolet light collides with an atom, it gives up its energy in two parts. Part of the energy goes into heat, increasing the kinetic energy of the entire atom. The other part of the energy goes into excitation, boosting an electron to a higher orbit. Upon de-excitation, this part of the energy is (Continued)

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	released as a photon of light. The secondary photon of light is of less energy than the primary (since some energy goes into heat), thus it is of a lower frequency.
c. fluorescent lamp--the common fluorescent lamp consists of a glass tube with electrodes at each end. Electrons are "boiled" off from the electrodes and forced to vibrate back and forth at high speeds. The tube is filled with very low-pressure mercury vapor that is excited by the impact of high-speed electrons. As the energy levels in mercury are relatively far apart, the resulting emission of light is of high frequency, mainly in the ultraviolet region. This is the primary excitation process. The secondary excitation process occurs when the ultraviolet light impinges upon a thin coating of powdery material made up of phosphors. The phosphors are excited by absorption of ultraviolet photons and give off a multitude of lower frequencies that combine to produce white light. Different phosphors can be used to produce different color lights.	Slide 5.1.1.21.--Fluorescent Lamp

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III. Comparing Different Light Sources A. Sources 1. Incandescent (filament lamps). 2. Mercury vapor. 3. Fluorescent. B. Incandescent Lamps 1. The hotter they burn, the whiter the light because of the movement of electrons. 2. However, the hotter they burn, the more wear and tear on the filament; thus decreasing the life of the lamp. 3. Decision to select depends on -electricity cost -efficiency 4. Electric cost low (shorter lamp life needed); where lamps are costly or labor cost of replacing them is high, a longer life is more economical. C. Mercury Lamps (High-Pressure Mercury Lamps) 1. More efficient (less generation of heat); about twice as efficient as filament lights. 2. Delayed starting and restarting. a. several minutes required for lamp to reach full brightness b. in case of power interruption, lamp will not restart until arc tube has cooled sufficiently for the mercury vapor to condense (about 5 minutes)	This disadvantage can be overcome by installing a filament light along with the mercury light.

TOPIC	REMARKS
c. ASA nomenclature used H33-1-CL/C H denotes mercury; 33-1 are ballast numbers; CL arbitrary letters designating bulb size, shape, material, and finish; C denotes color	
D. Fluorescent Lamps (Low-Pressure Mercury) 1. About three times as efficient as filament lamps. 2. Lime glass coating filters out all radiation that would be harmful to the eyes or skin. 3. Rapid start. a. in the past, fluorescent lamps were started with a starter that heated the electrodes at the end of the tube b. modern lamps are started with a ballast; have sufficient voltage to start lamp immediately 4. Give long life (1500 hours) a. lamps are affected by the number of starts; lamps will last longer if started less frequently	
IV. Summary A. What is light? B. What is an electromagnetic wave? C. How are electromagnetic waves produced? D. What is a photon?	A good way to summarize this information is to ask the questions indicated.

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TOPIC	REMARKS
E. How do the following lamps work? 1. Incandescent. 2. Mercury vapor. 3. Fluorescent. F. What are the advantages and disadvantages of the following lamps? 1. Incandescent. 2. Mercury vapor. 3. Fluorescent.	

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TOPIC	REMARKS
I. Introduction A. Review 1. Light has both wave-like behavior and particle-like behavior. 2. Light is radiant energy transported in photons that are carried by a wave field. 3. Sources. a. filament (explain how it works) b. mercury vapor c. fluorescent B. This Lesson 1. Behavior of light after it leaves the source. a. reflection b. refraction c. diffusion 2. The human eye. a. cones b. rods 3. Objective factors of seeing. a. size b. contrast c. brightness d. time 4. Light terminology. a. luminous flux b. luminous intensity c. illumination d. luminance e. reflectance 5. Survey procedures.	

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TOPIC	REMARKS
II. Behavior of Light	
A. Three Basic Characteristics	
1. Light travels in a straight line unless it is modified or redirected by means of a reflecting, refracting, or diffusing medium.	
2. Light waves pass through one another without alteration of either.	
3. Light is invisible in passing through space unless some medium (dirt or water droplets for example) scatters it in the direction of the eye.	
B. Light travels in a straight line unless modified by reflection, refraction, or diffusion.	Slide 5.1.2.1.--Light Travels in a Straight Line
1. Reflection.	
a. light travels in a straight line; when it is incident upon a surface, part of the light is reflected	Slide 5.1.2.2.--Law of Reflection
-metallic surfaces reflect almost 100% -clear glass surface, only a small part is reflected	Ratio of light reflected to that incident upon it is called "reflectance."
b. Law of reflection--angle of incidence is equal to the angle of reflection	
c. different types of reflection	
(1) specular reflection	Slide 5.1.2.3.--Specular
(2) diffuse reflection	Slide 5.1.2.4.--Diffuse
(3) spread reflection	Slide 5.1.2.5.--Spread
(4) mixed reflection	Slide 5.1.2.6.--Mixed

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TOPIC	REMARKS
2. Refraction--the bending of light as it passes from one transparent medium to another.	To explain the bending of light, the following discussion should take place.
a. velocity of light in different transparent media (1) in water, 75% of speed in vacuum (2) in glass, 67% of speed in vacuum (3) in a diamond, 41% of speed in vacuum	The speed of light is constant in nature. However, light has a lesser speed in a transparent medium. In water, light travels 75% of its speed in a vacuum; in glass, about 67% depending upon the type of glass; in a diamond, about 41%. When light emerges from these media, it again travels at its original speed. The students may have some trouble with this concept. From what they know about energy, this may seem to be strange behavior. If a bullet were fired through a board, the bullet would slow down in passing at a speed less than its incident speed. It loses some of its kinetic energy while interacting with fibers and splinters. But things are different with light. To understand this strange behavior, the student must consider the individual photons that make up a beam of light. They must also consider the interaction between the molecules and the photons they encounter. Incident photons interact with the electrons of these molecules. Think of the orbital electrons in molecules and atoms as tiny oscillators, where the electrons are attached to little springs that will resonate at certain frequencies and that are forced to vibrate over a range of frequencies. This range varies for different molecules. In clear glass, for example, this range (Continued)

TOPIC	REMARKS
	extends over the entire visible region. When a photon is incident upon a transparent medium such as glass, it is absorbed by a molecule at the surface. An electron in the absorbing molecule is set into vibration at a frequency equal to that of the incident photon. This vibration then causes the emission of a second photon of identical frequency. It is a different but indistinguishable photon. This second photon travels at 186,000 miles per second until it is quickly absorbed by another molecule in the glass; whereupon an electron is set into vibration, re-emitting a different but indistinguishable photon of its own. This absorption-re-emission process is <u>not</u> an instantaneous event. Some time is required for the process; and, as a result, the average speed of light through the material is less than 186,000 miles per second. The photon that enters the glass is not the same photon that leaves the glass.
b. illustration of refraction	Slide 5.1.2.7.--Refraction
(1) it is the slowing down of light upon entering the medium that causes the bending	
3. Diffusion--the spreading of light as it leaves a transparent or translucent material.	Slide 5.1.2.8.--Diffusion

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C. Light waves pass through one another without alteration of either.	
1. A beam of red light will pass directly through a beam of blue light unchanged in direction and color.	
D. Light is invisible in passing through space unless some medium, such as dirt or water droplets, scatters it in the direction of the eye.	
1. Scattering of light similar to resonance phenomenon in sound.	
2. Atoms behave like tuning forks and selectively scatter waves of appropriate frequency.	
3. A beam of light falling on atom causes electron to vibrate; the vibrating electron in turn radiates light in different direction.	
4. Example of scattering--search light at night; such light is seen because it is scattered by particles in atmosphere.	
III. Human Eye	
A. Structures	Slide 5.1.2.9.--Human Eye
1. Cornea (protective covering over the front of the eye).	
2. Pupil (opening in the iris).	
a. pupil contracts or expands due to muscles allowing more or less light to enter	
b. light first goes through cornea, then pupil	
3. Iris--colored portion of the eye.	

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4. Lens (transparent capsule behind iris). a. light passes from pupil into lens b. shape changes to focus objects at various distances c. lens controlled by ciliary muscles (ring shaped) 5. Retina (back part of the eye) a. lens focuses images (light) on the retina b. retina has receptors (1) cones (2) rods 6. Optic nerve. a. transmits information to the brain B. Retina Receptors 1. Rods (slim nerve cells). a. 100 million distributed on the retina b. sensitive to low levels of illumination c. have no color response d. located outside the foveal region, increasing in number as distance from foveal region increases e. outer portion of retina is composed chiefly of rods which do not afford distinct vision but are sensitive to movement and flicker f. when light hits rods, causes a breakdown of chemical rhodopsin (visual purple); chemical triggers optic nerve and sends impulse to brain	The chemical is photosensitive.

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2. Cones. a. approximately 6 million in retina b. make possible discrimination of fine detail c. make possible perception of color d. insensitive to low levels of illumination e. concentrated at fovea; rest dispersed among rods f. also contain photo-sensitive chemicals	
C. Characteristics of the Eye 1. Adaptation. a. adaptation to different levels of illumination b. done by change in size of pupils c. in dim light, chemicals in rods and cones are built up faster than they break down by light stimulation; the greater the concentration of chemicals, the lower the visual threshold. Adaptation to darkness is a matter of building up a surplus rhodopsin and the other chemicals	
d. cones adapt quickly to darkness (10 minutes) e. rods adapt more slowly (30 minutes or so) f. when adaptation is complete, rods are more sensitive than cones so to see an object in dark light, look away from the object and not directly at it	Note: Adaptation depends upon previous state of adaptation and the magnitude of change.

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2. Visual acuity--ability to discriminate the detail in field of vision.	Field of vision; 180° in horizontal plane 130° in vertical plane (60° above horizontal and 70° below horizontal)
a. 20/20 vision--ability to see clearly standing 20 feet from standard eye chart b. 20/50 vision--person sees 20 from eye chart what person with normal vision sees at 50 feet c. 20/10 vision--person sees at 20 feet what person with normal vision sees at 10 feet	
d. "blind spot"--a spot that has no visual acuity; the point where the nerves converge to form the optic nerve.	People are usually unaware of their blind spot. They compensate for it by moving their head and using their other eye.
D. Causes of Defective Vision 1. Astigmatism--inability to focus horizontal lines and vertical lines at the same time. 2. Myopia--objects focus in front of retina (nearsigntedness). 3. Hypermetropia--objects focus behind the retina (farsightedness). 4. Presbyopia--loss of elasticity in the lens due to age. 5. All defects can be corrected with glasses.	

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IV. Objective Factors in Seeing A. Seeing depends primarily on four factors. 1. Size. 2. Contrast. 3. Brightness. 4. Time.	
B. Size 1. Size depends upon the visual angle. a. the larger the object in terms of its visual angle with the eye, the more readily it can be seen b. visual acuity can be expressed as the reciprocal of the visual angle in minutes (this would be the measure of the smallest detail that can be seen)	Slide 5.1.2.10.--Size
C. Contrast 1. Brightness contrast--brightness between object to be seen and its immediate background or surroundings; brightness of object and surroundings should be about the same. 2. Color contrast--visibility is highest when color contrast is at a maximum.	
D. Brightness 1. Depends upon the intensity of light striking the object and the proportion of light reflected. 2. A white surface will have a much higher brightness than a dark surface.	

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E. Time 1. Seeing is not instantaneous--it takes time. 2. Eye can see detail in dim light if enough time is given. 3. Higher levels of illumination are required if quick seeing is required. F. All Four Factors Are Related 1. Small objects must have high contrast to be seen. 2. Low contrast objects must be large in size. 3. As brightness increases, contrast and size can decrease. 4. The more time available to see, the smaller the object can be and its contrast can be low. G. Engineer 1. Can control any variable; however, size is usually fixed. 2. Brightness and contrast are the easiest to manipulate. V. Terminology Used in the Science of Light A. <u>Luminous Flux</u>--The total radiant power emitted from a light source that is capable of affecting the sense of sight (time rate of flow of light). 1. Luminous flux is a definite quantity because the time element can usually be neglected. 2. Measurement is the lumen.	

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3. Lumen--the luminous flux emitted from a 1/60 cm^2 opening in a standard source included within a solid angle of one steradian.	Standard source consists of a hollow enclosure maintained at a temperature of the solidification of platinum (about 1773°C). It may be necessary to explain a solid angle in steradians. Slide 5.1.2.11.--Definition of Steradian A solid angle in steradians is given by $\Omega = \frac{A \cos \theta}{r^2}$ where Ω denotes the solid angle, A denotes the surface area of the sphere, R^2 denotes radius of the sphere, and θ represents the angle from the center of the sphere to surface area (A). If $\theta = 0°$, that is the surface area is perpendicular to center of the sphere, then $\cos \theta = 1$, and $\Omega = \frac{A}{R^2}$ Thus, a steradian can be defined as the solid angle subtended at the center of a sphere by an area A on its surface that is equal to the square of the radius (R) of the sphere; i.e., if $A = R^2$, then $\Omega = 1$. There are 4π steradians in a complete sphere. $\Omega = \frac{A}{R^2}$ $= \frac{4\pi R^2}{R^2}$ $= 4\pi$ steradians

TOPIC	REMARKS
4. A lumen is alternately defined as the luminous flux falling on a surface one square foot in area, every part of which is one foot from the point source having a luminous intensity of 1 candela (candlepower) in all directions.	
B. Luminous Intensity--The flux emitted by a point source per solid angle.	
1. Intensity = $\frac{\text{Flux}}{\Omega}$	Slide 5.1.2.12.--Intensity
2. Unit of luminous intensity is the lumen per steradian called "candela" or "candlepower."	It was called candlepower when the international standard was defined in terms of the quantity of light emitted by the flame of a certain candle. This particular or certain candle had a luminous intensity in a horizontal direction of approximately 1 candela. If a candle with a candlepower of 1 fell on a surface of one square foot (where every part of the surface was one foot from the candle) the amount of flux would be 1 lumen.
3. Note: Flux = Intensity Ω. If there is an isotropic source (one that emits light uniformly in all directions), then the total flux emitted would be Flux = 4π Intensity since the total solid angle for an isotropic source is 4π steradians.	

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	<u>Example Problems</u> If a spotlight is one foot from a wall with a candlepower of 1 candela and the beam covers an area of one square foot of the wall, what is the luminous intensity of the spotlight? <u>Solution</u> The <u>total</u> flux would be $\text{Flux} = 4\pi \text{ intensity}$ $= 4\pi \text{ 1 candela}$ $= 12.56 \text{ lumens}$ The light is concentrated into a solid angle given by $\Omega = \frac{A}{R^2}$ $= \frac{1 \text{ ft}^2}{(1 \text{ ft})^2}$ $= 1 \text{ steradian}$ Then the intensity would be $\text{Intensity} = \frac{\text{Flux}}{\Omega}$ $= \frac{12.56 \text{ lumens}}{1 \text{ steradian}}$ $= 1 \text{ candela}$ <u>Problem</u> A spotlight has a 100 candela bulb that concentrates a beam on a vertical wall. The beam covers an area of 60 ft^2 on the wall, and the spotlight is located 150 feet from the wall. Calculate the luminous intensity of the spotlight.

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TOPIC	REMARKS
	Solution

Total flux is computed as

$$\text{Flux} = 4\pi \text{ intensity} = 4\pi\ 100 \text{ candela} = 1256.64 \text{ lumens}$$

The total flux is concentrated by reflectors and lens into a solid angle computed by

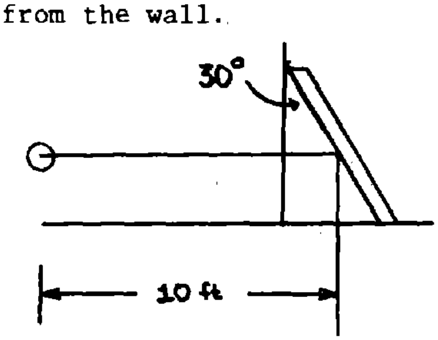
$$\Omega = \frac{A}{R^2} = \frac{60 \text{ ft}^2}{(150 \text{ ft})^2} = \frac{60 \text{ ft}^2}{22500 \text{ ft}^2} = .00256 \text{ steradians}$$

And thus, the intensity is given as

$$\text{Intensity} = \frac{\text{Flux}}{\Omega} = \frac{1256.64}{.00267} = 470{,}651.69 \text{ candela}$$

Problem

A spotlight has a 40 candela bulb that concentrates a beam on a wall 30° from vertical. The beam covers an area of 125 square feet on the wall and the beam is 10 feet from the wall.



Calculate the luminous intensity of the spotlight.

TOPIC	REMARKS
	Solution Total flux is computed as: $\text{Flux} = 4\pi \text{ intensity}$ $= 4\pi\ 40 \text{ candela}$ $= 502.65 \text{ lumens}$ The solid angle is computed as $\Omega = \frac{\text{Cos } \theta \text{ A}}{R^2}$ $= \frac{\text{Cos } \theta \text{ 125 ft}^2}{\text{100 ft}^2}$ $= 1.08 \text{ steradians}$ And the intensity is given as $\text{Intensity} = \frac{\text{Flux}}{\Omega}$ $= \frac{\text{502.65 lumens}}{\text{1.08 steradians}}$ $= 465.42 \text{ candela}$ Note: Steradian is dimensionless; thus, candela (lumens/steradian) and units of flux (lumens) are the same dimensionally.
C. Illumination--The density of luminous flux on a surface area $\text{Illumination} = \frac{\text{Flux}}{\text{Area}}$ where flux is measured in lumens and area in square feet illumination is in lumens per square feet. 1. Lumens/square feet sometimes called "foot-candle."	$\text{Illumination} = \frac{\text{Flux}}{\text{Area}}$ This relationship is important and is used as the basis for the lumen method.

TOPIC	REMARKS
2. If a lumen is defined as the flux falling on a surface area of one square foot, where every part of the surface is one square foot from a point source having a luminous intensity of one candela, then it is obvious that one lumen distributed uniformly over a one square foot surface produces the illumination of one foot-candle.	Slide 5.1.2.13.--Foot-Candle Note: $\text{Illumination} = \frac{\text{Flux}}{\text{Area}}$ $= \frac{\text{Intensity } \Omega}{\text{Area}}$ If $\Omega = \frac{\text{Area Cos } \theta}{R^2}$ Then Illumination = $\frac{\text{Intensity Area Cos } \theta}{R^2 \text{ Area}}$ $= \frac{\text{Intensity Cos } \theta}{R^2}$ In the special case where $\theta = 0^\circ$ (incident light is perpendicular to the surface), then $\text{Cos } \theta = 1$ and $\text{Illumination} = \frac{\text{Intensity}}{R^2}$ Units are lumens per distance squared.

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TOPIC	REMARKS
	<u>Problem</u> A bulb has a luminous intensity of 465.42 candela and is located 10 feet from a surface whose area is 125 ft^2. The luminous flux makes an angle 30^o with the normal surface. What is the illumination? What is the luminous flux? <u>Solution</u> $\text{Illumination} = \frac{\text{Intensity Cos } \theta}{R^2}$ $= \frac{465.42 \text{ candela Cos } 30^o}{(10 \text{ ft})^2}$ $= 4.03 \text{ candela/ft}^2$ or foot-candles Flux, if $\text{Illumination} = \frac{\text{Flux}}{\text{Area}}$ then Flux = Illumination • Area $\text{Flux} = 4.03 \text{ candela/ft}^2 \cdot 125 \text{ ft}^2$ = 503.75 lumens
VI. Measurement of Light A. Foot-Candle Measurements 1. Foot-candle meter. 2. How it works. a. barrier layer cells b. the cells consist of a film of light-sensitive material mounted on a metal base and covered with a very this translucent layer of metal spattered on its outer surface	Slide 5.1.2.14.--Foot-Candle Meter Slide 5.1.2.15.--How a Foot-Candle Meter Works

TOPIC	REMARKS
c. light striking the cell surface causes the semi-conducting light-sensitive material to emit electrons that are picked up by a metal collector in contact with the translucent front electrode. A potential difference is then picked up between the collector and the base plate;	
d. and when the microammeter is connected between them, it measures the current generated by the cell	
e. since the current is proportional to the intensity of the incident light, the meter can be calibrated to read directly in foot-candles	
3. Instruments must be	Note: They must be corrected for color because the response of the light-sensitive cells to the various wavelengths of the visible spectrum is different from that of the human eye.
a. color corrected	
(1) most instuments have color-correcting filters	
b. cosine corrected	
(1) adjusts for the angle of reflected light	
c. calibrated frequently	
(1) accuracy ± 5 percent	
d. note: luminance meters can be used to measure illumination if the reflectance is known; i.e., illumination = luminance ÷ reflectance	

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TOPIC	REMARKS
B. Luminance (Brightness) Meters	
1. Photoelectric tube.	Slide 5.1.2.16.--Photoelectric Tube
a. the instrument is aimed at the surface to be measured and a lens focuses the image on a small area of the tube which produces a current proportional to luminance b. current is read in a microammeter calibrated in foot-lamberts	
2. Visual illuminance meter.	Slide 5.1.2.17.--Visual Illuminance Meter
a. uses an optical system to bring to the eyes of the observer, side by side, the surface to be measured and a comparison field inside the meter	
C. Reflectance	
1. Can be measured by a cell-type foot-candle meter. 2. Two procedures--the more accurate way follows.	
a. a piece of matte material at least one square foot, the reflectance of which is known b. white blotting paper (80% is suitable) c. blotting paper is placed against the surface to be measured; meter is held 2 to 4 inches away with the cell facing the paper (Reading A) d. blotting paper then removed, without moving the meter, and Reading B is noted	

TOPIC	REMARKS
e. reflectance of the surface is then given as $\frac{\text{Reading B}}{\text{Reading A}} \times .80$	
D. Other Measurements That Should Be Taken in a Field Survey	
1. Temperature near the lamp. 2. Voltage is measured at the luminaire output.	
VII. Survey Procedure	
A. "How to Make a Lighting Survey" developed by the Illuminating Engineer Society provides uniform detailed lighting procedures and a form with instructions on how to use the form.	
B. The survey includes reporting on the following information:	
1. Description of the illuminated area.	Slide 5.1.2.18.--Lighting Survey
a. room dimensions b. colors c. reflectance d. condition of room surface e. temperature surrounding the lights	
2. Description of the <u>general</u> lighting system.	If time permits, point out the following:
a. quantities b. conditions c. wattages d. lamps e. distribution f. spacing g. mounting	1. Cleanliness of the fixtures, walls, and ceiling should also be indicated (since they act as secondary reflectors). 2. The length of time the lamps have been burned is also important to note. This is particularly true with fluorescent lamps. 100 hours before measurement should be taken.
3. Description of any supplementary lighting that might be used.	

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TOPIC	REMARKS
4. Description of instruments used. 5. ± illumination measurements. a. operator must be aware not to cast shadows b. operator must be aware not to reflect additional light with his clothing c. test surfaces should be as close as possible to the working plane; if there is no definite working plane, take measurements in a horizontal plane 30 inches above the floor 6. Luminance measurements.	
C. Evaluation of Results 1. Illumination levels (for compliance with recommended levels). 2. Luminance values (for compliance with luminance rates for visibility and safety). 3. Indications of the degree of comfort and pleasantness in the area. 4. To determine deficiencies. 5. Maintenance schedule.	Slide 5.1.2.19.--Evaluation of Results

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TOPIC	REMARKS
I. Introduction A. Review 1. Last lesson discussed many things; including discussion of four factors involved in seeing industrial tasks. a. size b. contrast c. brightness d. time 2. This lesson continues discussion of factors involved in seeing, particularly brightness. B. Lumen Method 1. Lumen method of designing lighting systems will also be discussed. II. Design of a Lighting System A. Quantity of Light 1. The obvious measure of adequacy of lighting system is the amount of light it provides. 2. Research has shown that: a. illumination of thousands of foot-candles is required to see dark, low-contrast tasks as easily as light-colored tasks of high contrast under low levels b. for light-colored, high-contrast tasks, level for good visibility is low c. however, there are other factors involved; the suggested minimum foot-candles is 30	

TOPIC	REMARKS
3. Recommended foot-candles. a. Illumination Engineering Society b. published recommended levels of illumination for specific visual tasks (1) level based upon characteristics of task, visual performance requirement (2) recommendations are to provide guides, not regulatory minimum standards for safety (3) values or levels should be considered minimum only	
(4) in order to insure the minimum levels, initial higher level should be provided (5) the recommended levels do not take into consideration the wearing of goggles	This is because of maintenance of the system or lights. They are minimum levels on the task when the lighting system and room surfaces have depreciated to their lowest levels before maintenance procedures are effected (cleaning, relamping, painting, etc.).
NOTE: If goggles are worn, the level of illumination should be increased in accordance with the absorption of the goggles.	At this time, distribute copies of the Recommended Levels of Illumination. Note about the recommended levels: 1. The illumination level specified is to be provided on the work surface, whether this is to be horizontal, vertical, or oblique.

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TOPIC	REMARKS
	2. Where there is no definite work area, it is assumed that the illumination is measured on a horizontal plane 30 inches above the floor. 3. Some values are equivalent to sphere illumination. The use of this technique is outlined in the IES Handbook, beginning on page 3-20.
(6) levels reflect approximate seeing ease; thus, the recommended levels are relative; this also means that they give a rough indication of the relative severity of various seeing tasks	
2. Quantity of light also depends upon distribution of light or illumination.	
a. light for seeing or production--usually desirable to position the luminaires to provide uniform general lighting over the entire area	
b. ratio of maximum footcandles under the luminaires to the minimum between them should never be greater than 3 to 2; best results approach unity	That is, units with wide distribution characteristics can be spaced further apart for the same mounting height, than those with more concentrated distribution. Maximum space-to-height or seeing height ratios for various types of equipment are supplied by the manufacturer.
B. Quality of Light	
1. By definition, quality of light refers to the brightness distribution.	Note: Quantity alone does not insure good illumination.
a. high luminance may contribute to glare	

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TOPIC	REMARKS
b. glare	
(1) discomfort glare	Produces discomfort, but does not necessarily interfere with visual performance or visibility.
(2) disability glare	Reduces visibility of object to be seen.
c. causes of glare	
(1) light bright sources (direct glare) (2) bright reflection (reflected glare)	
d. control of glare	
(1) glare is reduced rapidly as the source is move away from the line of vision (2) shielding	
-at least 25° down from the horizontal -45° is preferable	In other words, brightness of bare lamps preferably should not be seen when looking in the range from straight ahead to 45° above the horizontal.
e. veiling reflections	
(1) when reflected glare is produced, it becomes a veiling reflection because in most cases it will veil the task (reduce visibility) by reducing its contrast (2) veiling reflections can be reduced by: increasing the level of illumination or using layouts and luminaires designed to limit the light directed toward the task that will be reflected into the eyes	

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TOPIC	REMARKS
	Additional notes about glare: 1. Glare is influenced by characteristics of the room and use of the luminaires. 2. Luminaire brightnesses that are quite comfortable in a small office where the units are out of range of vision may be excessive in a larger room where the luminaires are farther away and more nearly approach the line of vision. 3. Luminaires that do not have objectionable high brightnesses may, if mounted in a large group, present a total that is uncomfortable. This usually results when some types of fluorescent luminaires are mounted across the line of sight--with relatively low ceilings. 4. Color of walls and ceilings is important.
2. Brightness ratio or brightness contrast. a. different brightness in area of immediate task and immediate background or surrounding area b. may not cause glare but is detrimental to good lighting quality	
c. if there is a difference in brightness between the task and surrounding background, the eyes will have to adapt between the task and surroundings continually--it takes some time for the eyes to adapt; therefore, visibility of the task will be affected	This implies that the best situation is one where the brightness of the task and the surrounding area should be the same.

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TOPIC	REMARKS
d. brighter surroundings tend to attract the eye away from the task	
e. to reduce the effects, luminance ratios are recommended	Slide 5.1.3.1.--Luminance Ratios Be sure to explain the slide.
f. comfortable brightness ratios require a careful study of many factors (1) light sources (2) type of luminaires (3) reflection characteristics of ceilings, walls, floor, and furnishings	Slide 5.1.3.2.--Reflection Factors
3. Diffusion	Recall the three aspects of quality discussed so far: 1. Amount of brightness (glare) 2. Brightness ratio or contrast 3. Diffusion
a. definition--light coming from many directions as opposed to light from one direction is said to be diffuse light	
b. measured in terms of the absence of <u>sharp</u> shadows	Note: The degree of diffusion depends upon the type of work to be performed. Perfectly diffuse light is ideal illumination for many critical seeing tasks (schools and offices). Where polished metal surfaces must be viewed, a highly diffuse light is essential to prevent annoying specular reflections. In other cases, direct lighting may be more important or desirable. For example, surface irregularities that are almost invisible under diffuse light may be clearly revealed in light directed at a glazing angle.

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TOPIC	REMARKS
c. diffusion is achieved by -multiple light sources -large or low brightness luminaires -indirect or partial indirect lighting in which the ceiling and walls become secondary sources -light-colored matte finishes on ceilings, walls, furniture, and even the floors	Fluorescent direct luminaires ordinarily provide more diffuse illumination than incandescent direct luminaires, and large-area hoods or diffusing panels provide still greater diffusion.
4. Color. a. subject of color is complex b. however, for performance of ordinary visible tasks no one color light source has an advantage over any other c. color must be considered in specialized applications -color matching tasks -color discrimination tasks -certain inspection tasks	Lamps come in many different colors.
III. Types of Luminaires A. Classifications 1. General. 2. Supplemental.	Selection depends upon: 1. Physical characteristics of the room. 2. Type of work performed. 3. Conditions of maintenance.

TOPIC	REMARKS
B. General Subidivided into	
1. Indirect lighting.	
a. 90-100% of the light output is directed toward the ceiling at angles above the horizontal	Slide 5.1.3.3.--Classification of Luminaires
b. ceiling reflects light to walls and task area; i.e., ceiling acts as the secondary source of light	
c. produce diffuse lighting -even distribution -minimum of shadows -minimum of reflected glare -walls and ceiling should be light-colored -walls and ceiling should have matte finish	
2. Semi-direct lighting.	
a. 60% to 90% is directed toward the ceiling at angles above the horizontal while the balance is directed downward	
b. same advantages as indirect lighting but usually more efficient; it is sometimes preferred to achieve a desired luminance ratio between the ceiling and high-level installation	Note: The diffusing medium is glass or plastic of a lower density than that used in indirect equipment.
3. General diffuse or direct-indirect lighting.	
a. 40% to 60% of the light is directed downward at angles below the horizontal; i.e., the major portion of the light comes directly from the luminaire	Since some light is directed to the ceilings and the walls, they should be light colored.

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TOPIC	REMARKS
b. difference between general diffuse and direct-indirect is the amount of light produced in the horizontal direction	
-general diffuse lighting usually has an enclosing globe that distributes light nearly uniformly in all directions, while direct-indirect lighting produces very little horizontal light (due to density of its side panels)	
4. Semi-direct lighting.	
a. 60% to 90% is directed downward at angles below the horizontal	
b. small portion of light is directed to the ceiling; however, this small portion helps to lower the brightness contrast	
5. Direct lighting.	
a. 90% to 100% is directed downward at angles below the horizontal	
b. very efficient, but (1) creates shadows (2) creates glare	Point out that ceiling lights in large areas with cellular louvers are direct light but can cut down on glare and give an indirect lighting effect.
	Slide 5.1.3.4.--Lighting Systems
IV. Illumination Methods	
A. Types of Methods Employed	
1. General. 2. Localized general. 3. Supplemental.	

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TOPIC	REMARKS
B. General Lighting 1. Definition--the arrangement of lighting equipment so that a uniform level of illumination is produced. 2. Factors affecting uniform distribution of light--light location. a. physical characteristics of the room b. the level of illumination desired c. appearance of the finished installation 3. How to obtain uniform lighting.	Slide 5.1.3.5.--General Lighting
a. after computing the number of luminaires needed to produce the desired quantity of light using the lumen method, a rough approximation of location should be made	Inform the students that later in this lesson the lumen method will be discussed.
b. purpose of rough estimation is to get an even distribution c. guidelines (1) determine total number of luminaires distributed to total is evenly divisible by the number of rows	
(2) exact distance between fixtures is determined by dividing the length of the room by the number of luminaires in a row, allowing about 1/3 of the distance between the wall and the first unit	Slide 5.1.3.6.--Lighting Arrangement for General Lighting

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TOPIC	REMARKS
(3) in a similar manner, distance between rows is width of room divided by number of rows, with about 1/3 of distance left between the side and the first row.	Note: In high ceilings, that distance may be up to one-half of the luminaire spacing. Inform the students that this procedure will be discussed in more detail in the discussion of the lumen method.
B. Localized General Lighting 1. Definition--the positioning of general lighting equipment with reference to particular work areas where high intensities are necessary, with the spill light from the same luminaires usually providing sufficient illumination for adjacent areas. 2. Luminaires of the direct, semi-direct, or direct-indirect are usually employed (since a substantial direct component is essential).	
C. Supplementary Lighting 1. Definition--the provision of relatively high intensity at specific work points by means of direct lighting equipment used in conjunction with general or localized general illumination. 2. Supplemental lighting is frequently necessary where especially critical seeing tasks are involved. 3. Equipment used in this way has different distributionaal qualities.	

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TOPIC	REMARKS
4. Care should be taken to keep a reasonable relationship between the intensities of the general illumination and supplemental lighting, since an excessive luminance ratio between the work point and its surrounding creates an uncomfortable seeing condition.	
V. Other Factors to Consider When Designing a Lighting System	
A. Choice of Light Source	
1. Filament. 2. Mercury vapor. 3. Fluorescent	
B. Heat produced from the source	
C. Proper candle-power distribution	
D. Efficiency of the lamp or light source	
E. Electrical Features	
1. Use equipment that conforms to underwriters' specifications. 2. Use adequate type of wiring and circuits.	
F. Mechanical structure to support fixture	
G. Appearance (decoration)	
H. Color of lights	
I. Maintenance	
1. Three things to consider in maintenance	
a. the light source (life of) b. the luminaire c. the room surface	

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TOPIC	REMARKS
2. The life of the light source.	
a. length of life is different for filament, mercury vapor, and fluorescent lamps	
b. output is different during the life of the lamp	This is why recommended foot-candles are minimums.
(1) mercury vapor and fluorescent lights last longer; however, near the end of their life, they are about 75% of the output of the beginning of their life	
c. replacement of light source	
(1) new lamps should be installed before the old ones burn out	
(2) schemes include	
-systematically replacing lamps after X number of hours in certain area.	This procedure is called "group relamping." Two routines of this procedure can be used: 1. All the lamps in the area can be replaced at one time. 2. Or distributed portions may be replaced at separate intervals. The latter method has the advantage in that it results in less variation in the illumination.
-replacing lamps as they burn out.	This procedure results in less variation. Note: The replacement scheme is determined by the accessibility of the equipment and cost of individual replacement.

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TOPIC	REMARKS
3. Luminaires.	
a. do not function efficiently when covered with dirt	The dirt depends on the characteristic environment of the room and type of activity. This is because light is required to travel through the layer of dust and because the dust can change the distribution characteristics of the equipment. This is particularly true where the lamp is to provide a direct beam of light--the dirt makes the resulting light diffuse.
b. need to plan ahead for cleaning the equipment -look at how the fixture comes apart (hinges are useful) -is a stepladder needed -are catwalks necessary -are messenger cables the best -are swing-type lamps the best	
c. schedule of cleaning -depends upon how dirty the environment is -try to make cleaning coincide with replacement schedule; this will reduce labor costs	
4. Room surfaces.	
a. if lighting system is indirect lighting, the dirt on the room surfaces may affect the light b. schedule of cleaning depends on the conditions	

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TOPIC	REMARKS
VII. Lumen Method of Lighting Design	

VII. Lumen Method of Lighting Design

A. Brief Review

1. So far, this lesson has discussed most of the ingredients involved in designing a lighting system.

   a. quantity of light (recommended standards)
   b. quality (brightness ratio and glare)
   c. luminaire classification

      -indirect
      -semi-indirect
      -general diffuse--direct-indirect
      -semi-direct
      -direct

   d. illumination methods

      -general lighting
      -localized general lighting
      -supplemental lighting

   e. maintenance factors

      -light source
      -luminaires
      -room surfaces

2. Remainder of this lesson will discuss the lumen method.

B. Lumen Method of Calculation

1. Description--A way for computing the average illumination throughout the room.

   a. procedure is good for general lighting

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TOPIC	REMARKS
b. however, procedure is <u>not</u> very good when the general localized or supplemental method is used; in these cases, one must compute the illumination at the point where the actual seeing task is located (the average illumination throughout the room is meaningless in this case)	In the case of general localized lighting and supplemental lighting, the point-by-point method is used to calculate the quantity of illumination. Point-by-point method is beyond the scope of this course and will not be discussed.
c. thus, all calculations will be for generalized lighting (where uniform lighting is needed)	Note: Some people even prefer point-by-point method for generalized lighting.
2. Procedure for lumen method.	Remember, this assumes uniform light throughout the room.
a. analyze the seeing task and the work environment (1) how should the task be portrayed by the light (2) should the lighting be diffuse or directional (or some combination of both) (3) are shadows important (4) is color important (5) what is the area atmosphere and, therefore, the type of maintenance characteristics needed (6) what are the economics of the lighting system	

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TOPIC	REMARKS
b. from above data, determine the following: (1) what level of illumination is needed for the task (use the recommended standards as a minimum) (2) type of luminaires needed (use manufacturer's catalogue to determine this) c. having determined the luminaires to be used and the illumination needed, then it is possible to calculate the number of luminaires needed to produce that illumination (1) lumen method is based upon the definition of a foot-candle	
$$\text{Foot-candle} = \frac{\text{lumens striking area}}{\text{square feet of area}}$$	Slide 5.1.3.7.--Basic Lumen Formula
(2) by knowing initial lumen output of each lamp (published by lamp manufacturer), the number of lamps installed in the area and the square feet of area, one can calculate the lumens per square foot generated initially in the area. However, this value differs from the foot-candles in the area because -some lumens are absorbed in the luminaires -dirt buildup reduces the number of lumens	

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TOPIC	REMARKS
-gradual depreciation in lumen output of the lamps reduces the number of lumens these factors must be considered unless one is interested only in the initial lumens in the area	
(3) These factors plus others are taken into consideration in the basic lumen method, and the formula becomes	Slide 5.1.3.8.--Lumen Method Formula
Foot candles = $\frac{\text{lamps per luminaire x lumens per lamp x coefficient of utilization x light loss factor}}{\text{area per luminaire}}$ or Number of Lamps = $\frac{\text{Foot-candles x area}}{\text{lumens per lamp x coefficient of utilization x light loss factor}}$	
3. Understanding the formula. a. first steps are to: (1) determine the foot-candles needed for the task (using the recommended standards) (2) determine type of luminaires needed from environmental factors, using manufacturers' data	

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TOPIC	REMARKS
b. determine coefficient of utilization	
(1) definition--the ratio of the lumens reaching the work area (assumed to be a horizontal plane 30" above the floor) to the total lumens generated by the lamps	
(2) a factor that takes into account -efficiency and distribution of luminaires -luminaire mounting height -room proportions -reflectance of walls, ceiling, and floor	Note: Because of multiple reflections within a room, some light passes downward through the imaginary work plane more than once; under some circumstances, this may cause the coefficient of utilization to be larger than 1.0.
(3) in general, the higher and narrower the room, the larger the percentage of light absorbed by the walls, and the lower the coefficient of utilization. Rooms are classified by the room cavity ratio	
(4) coefficient of utilization usually determined from a table; to use table, need to know	Slide 5.1.3.9.--Coefficient of Utilization Table Explain table.
-category of luminaire	Will be discussed later.
-ceiling cavity reflectance	

TOPIC	REMARKS
-wall reflectance -room cavity ratio (RCR)	
(5) computing room cavity ratio (RCR)	Slide 5.3.1.10.--Cavities
-every room can be broken up into 3 cavities; ceiling cavity, room cavity, floor cavity--each having a cavity radio; ceiling cavity ratio (CCR), room cavity ratio (RCR), floor cavity ratio (FCR); each computed by	
Cavity ratio = $\frac{5h(\text{room length} + \text{room width})}{\text{room length} \times \text{room width}}$	
where h is the height of the cavity	Example A room is 40 ft long, 20 ft wide, and 12 1/2 feet high; and the luminaires are mounted 2 ft from the ceiling, and the work plane is 2 1/2 ft from the floor. What is the ceiling cavity ratio? Ceiling cavity ratio computed as follows: Ceiling cavity ratio = $\frac{5h\ (\text{room width} + \text{room length})}{\text{room width} \times \text{room length}}$ where h = 2 ft since the luminaires are mounted 2 ft below the ceiling. (Continued)

TOPIC	REMARKS
	$CCR = \frac{5 \cdot 2\ ft\ (40\ ft + 20\ ft)}{40\ ft \times 20\ ft}$
	$= \frac{10\ ft\ (60\ ft)}{800\ ft^2}$
	$= \frac{600\ ft^2}{800\ ft^2}$
	$= \frac{6}{8}$
	$= 0.75$
	Now ask the students to compute the room cavity ratio (RCR)
	$RCR = \frac{5h(\text{room width} + \text{room length})}{\text{room width} \times \text{room length}}$
	where h = 8 ft (distance between luminaire and working plane)
	$RCR = \frac{5 \cdot 8\ ft\ (40\ ft + 20\ ft)}{40\ ft \times 20\ ft}$
	$= \frac{40\ ft\ (60\ ft)}{800\ ft^2}$
	$= \frac{2400\ ft^2}{800\ ft^2}$
	$= 3.0$
	Now compute floor cavity ratio.
	$FCR = \frac{5 \cdot 2\ 1/2\ ft\ (40\ ft + 20\ ft)}{800\ ft^2}$
	$= 0.94$
-an alternate expression can also be used to compute these cavity ratios	
$\text{Cavity Ratio} = \frac{10h}{\text{room width}} \times \text{Gaysunas Ratio}$	Slide 5.1.3.11--Gaysunas Ratio

TOPIC	REMARKS
	Using Gaysunas Ratio Table, compute room cavity ratio for the example given above. From Gaysunas Table, a room 40 ft long and 20 ft wide has a Gaysunas ratio of 3/4; thus $RCR = \frac{10h}{20} \times 3/4$ $= \frac{10 \cdot 8\ ft}{20\ ft} \times 3/4$ $= \frac{80\ ft(3)}{20\ ft(4)}$ $= \frac{240\ ft}{80\ ft}$ $= 3.0$
-tables are also available	Slide 5.1.3.12.--Room Cavity Tables
-this now gives one of the four things needed to determine the coefficient of utilization	
(6) wall reflectance--determined by measurements discussed in last lesson (usually expressed as a percent)	
(7) determine ceiling cavity reflectance--usually looked up from a table (Effective Ceiling Cavity Reflectance vs. Actual Cavity Reflectance)	Slide 5.1.3.13--Effective Cavity Reflectance Table Explain difference between effective cavity reflectance and actual cavity reflectance.

TOPIC	REMARKS
	Example using Effective Cavity Reflectance table. Room dimensions: 20 ft wide, 40 ft long, 12 1/2 ft high. Work plane: 2 1/2 ft above floor Mountings: 2 ft below ceiling Ceiling reflectance: 80% Wall reflectance: 50% Determine effective ceiling cavity reflectance. First, compute ceiling cavity ratio (CCR) $CCR = \frac{5h(\text{room width} + \text{room length})}{\text{room width} \times \text{room length}}$ $= \frac{5 \cdot 2\text{ ft }(40\text{ ft} + 20\text{ ft})}{40\text{ ft} \times 20\text{ ft}}$ $= 0.75$ Using table, entering 0.75 as the cavity ratio; wall reflectance, 50%; and actual ceiling reflectance, 80% (base reflectance); the effective ceiling cavity reflectance is between 69 and 71, or about 69.68%.
(8) once category of lamp is determined, the coefficient of utilization can be looked up	Example: Using Slide 5.1.3.9., have the student determine coefficient of utilization from table, if Room dimensions: 40 ft by 20 ft by 12 1/2 ft Work plane: 2 1/2 ft from floor Mounting: 2 ft from ceiling Ceiling reflectance: 80% Wall reflectance: 50% Luminaires: Category III with a distribution of 0% up, 79% down.

TOPIC	REMARKS
	Then, what is coefficient of utilization?
	First, compute RCR.
	$RCR = \frac{5h(\text{room width} + \text{room length})}{\text{room width} \times \text{room length}}$
	$= \frac{5\ (8\ ft)(40\ ft + 20\ ft)}{40\ ft \times 20\ ft}$
	$= 3.0$
	Then compute CCR.
	$CCR = \frac{5h(\text{room width} + \text{room length})}{\text{room width} \times \text{room length}}$
	$= 0.75$
	Next determine effective ceiling cavity reflectance using appropriate table: Effective Ceiling Cavity Reflectance = 70% ~ 69.68%.
	Next determine coefficient of utilization. Using the appropriate table, the coefficient of utilization would be about 0.64.
	<u>Optional Discussion</u>
	If the actual floor cavity reflectance is 10% or 30%, a correction may be necessary depending on the accuracy desired. For 30% effective floor cavity reflectance, multiply the appropriate factor below. For 10% effective floor cavity reflectance, divide by the appropriate factor.
	Slide 5.1.3.14.--Effective Floor Cavity Reflectance Correction

TOPIC	REMARKS
C. Next factor to determine in the use of the formula is the light loss factor.	
1. Illumination is in a process of change due to -lamp ages -accumulation of dirt, etc. These factors contribute to the loss of light.	
2. There are eight factors to consider; the total light loss factor is the product of these contributing factors. Only four of these factors will be discussed.	The final light loss factor is the product of all contributing factors; i.e., it is the ratio of the illumination when it reaches the lowest level at the task just before corrective action is taken to the initial level if none of the contributing factors were considered.
a. Ballast Performance--The Certified Ballast Manufacturers Association specifications for fluorescent lamps require a ballast to operate a fluorescent lamp at 95% of the output of the lamp. When operated at a reference ballast (the reference ballast is a laboratory standard). For ballast bearing CMB label use .95; if no CMB label, estimate a lower factor	
b. Luminaire Reflectance and transmission changes--this effect is usually small but may be significant over a long period of time for luminaires with inferior finishes or plastics. Comprehensive data are not available. Usually manufacturer will list factor.	

Lesson Outline

Lighting Design	Module 5 Unit 1 Lesson 3

TOPIC	REMARKS
c. Lamp Lumen Depreciation--The contributing loss factor for fluorescent lamps is usually expressed as a ratio of the lumen output of the lamp at 70% of rated life to the initial 100-hour value.	Slide 5.1.3.15.--Lamp Lumen Depreciation
d. Luminaire Dirt Depreciation--This factor varies with the type of luminaire and the atmosphere in which it is operated. Luminaires are divided into six categories. After determining the category, the luminaire dirt depreciation factor can be read from one of five curves.	Slide 5.1.3.16.--Dirt Depreciation Curve Have students practice computing the Light Loss Factor (LLF). Given the following, compute the LLF. 1. Ballast Performance = 0.95 2. Luminaire Reflectance and Transmission = 0.98 3. Lamp Lumen Depreciation--Assume fluorescent lamp F96T12/CW/HO, Category IV, which burns 12 hrs per start. 4. Dirt Depreciation--Assume Clean Category VI replaced every 12 months. LLF = .95 x .98 x .84 (looked up from table) x .86 (from curves) = .672

Lesson Outline	
Lighting Design	Module 5 Unit 1 Lesson 3

TOPIC	REMARKS
D. Using the Formula	
Number of Lamps = $\frac{\text{Foot-candles x Area}}{\text{Lumens per lamp x coefficient of utilization x light loss factor}}$	Write the formula on the chalkboard.
Number of Luminaires = $\frac{\text{Number of lamps}}{\text{Lamps per luminaire}}$	
Compute the number of luminaires for the following:	
Room: 20 x 40 x 12 1/2 (regular office) Mounting: 2 feet from ceiling Work plane: Assume 2 1/2 feet from floor Ceiling reflectance: 80% Wall reflectance: 50% Floor reflectance: 20% (assume)	
Category IV luminaire F96T12/CW/HO opaque side 75% - 5% distribution	
Ballast performance = .95 Luminaire reflectance = .98 Lamp lumen depreciation--Assume replaced every 12 months. Assume condition to be clean.	
1. Compute ratio of room length to room width $\frac{40}{20} = 2.0$	
2. Compute ceiling cavity ratio. $\text{CCR} = \frac{10h}{\text{Room width}} \times \text{Gaysunas ratio}$ where h = 2 feet (height mounted) $\text{CCR} = \frac{(10)2 \text{ ft}}{20 \text{ ft}} \times .75$ CCR = 0.75	
3. Determine effective ceiling reflectance using the table 70%	

Lesson Outline	
Lighting Design	Module 5 Unit 1 Lesson 3

TOPIC	REMARKS
4. Compute the room cavity ratio. $RCR = \frac{10h}{\text{Room width}} \times \text{Gaysunas ratio}$ $= \frac{10(8)\text{ ft}}{20\text{ ft}} \times .75$ $= 3.0$	
5. Look up coefficient of utilization 0.45 (using 75% effecting ceiling reflectance)	
6. Compute light loss factor. a. Ballast = .95 b. Reflectance = .98 c. Lumen depreciation (look up 12 hours) = .84 d. Dirt depreciation = .86 (look up on curve) $.95 \times .98 \times .84 \times .86 = 0.672$	
7. Look up foot-candles needed for regular office tasks in Recommended Standards 100 foot-candles	
8. Compute the number of lamps $\text{Number of lamps} = \frac{100 \times 20 \times 40}{\text{output} \times .45 \times .672}$ where lumens per lamp output = 9000 lumens $\text{Number of lamps} = \frac{80{,}000}{9000 \times .45 \times .672}$ $= \frac{80{,}000}{272.16}$ $= 29 \text{ lamps}$	
9. Compute the number of luminaires where there are two lamps per luminaire $\frac{29}{2} = 14.5$	

Lesson Outline	
Lighting Design	Module 5 Unit 1 Lesson 3

TOPIC	REMARKS
10. Figure out how luminaires should be mounted. a. recall 1/3 b. 2 rows of 7	
VIII. Point-by-Point Method A. Method to calculate the amount of light hitting a specified task. 1. Can be used for general, localized general, and supplemental lighting. 2. Method is complicated.	For those interested, see Westinghouse Lighting Handbook, Revised 1974; or General Electric Photometric Data and Sample Calculation

Self-Test	
Industrial Illumination	Module 5

1. Write a brief description of light.

2. Which radiates more energy, infrared light or green light? Explain.

3. When light travels through one transparent medium to another, why does it appear to bend?

4. Explain how the human eye perceives color.

5. List four objective factors in seeing objects.

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

6. A tungsten filament lamp has an intensity of 800 candela and is located 2 feet from a surface whose area is 0.25 feet. The luminous flux makes an angle 30° with the normal of the surface. What is the illumination?

7. How many luminaires should go into this warehouse where there are active fine conditions? What is the best arrangement of the luminaires?

Room Dimensions

144' long x 48' wide x 13' high

Luminaires:

-distribution pattern 17% up, 69% down, Category I
-lamps will be FT2T12/CW/HO
-lamps will work 18 hours/start
-ballast is certified by Ballast Manufacturers Association
-conditions in the warehouse are considered dirty
-luminaires will be cleaned every 24 months
-luminaire reflectance about 80%

Mounting and Reflectance Information:

-assume floor reflectance of 20%
-assume mounting is 2 1/2' from ceiling
-assume work plane is 2 1/2' from floor
-wall reflectance is 30%
-base ceiling reflectance is 80%
-assume <u>no</u> adjustment for floor cavity ratio is required

Self-Test (Answers)	
Industrial Illumination	Module 5

1. Write a brief description of light.

   Light has both electromagnetic wave properties and particle (photon) properties; thus, light is radiant energy transported in photons that are carried by wave fields.

2. Which radiates more energy, infrared light or green light? Explain.

   The green light would have more energy than the infrared light. Green light has a smaller wavelength than infrared light. Since both "lights" travel at the same speed and the frequency of green light is higher than the frequency of infrared light, thus, according to Planck's expression

   $E = hf$ *where h denotes Planck's constant*

   green light would produce a higher energy, E, than infrared light.

3. When light travels through one transparent medium to another, why does it appear to bend?

   When light goes from air to glass, for example, the photon that is incident upon the glass is absorbed by the matter of the glass. An electron in the absorbing atom is set into vibration at a frequency equal to that of the incident photon. The vibration then causes the emission of a second photon of identical frequency. This second photon travels at 186,000 miles per second until it is quickly absorbed by another atom in the glass, whereupon another electron is set in vibration, re-emitting a different photon. This absorption-emission process is not an instantaneous event. Thus, the average speed through the material is less than 186,000 miles per second. The different speed between the two media causes the light to bend.

4. Explain how the human eye perceives color.

   The cones in the eye contain photosensitive chemicals. Different combinations of different chemicals trigger to optic nerve and result in the seeing of color.

5. List four objective factors in seeing objects.

   a. *Size of object*

   b. *Contrast (color, brightness)*

   c. *Brightness*

   d. *Time*

6. A tungsten filament lamp has an intensity of 800 candela and is located 2 feet from a surface whose area is 0.25 feet. The luminous flux makes an angle 30° with the normal of the surface. What is the illumination?

$$Illumination = \frac{Flux}{Area}$$

$$= \frac{Intensity\ \Omega}{Area}$$

$$= \frac{Intensity\ Area\ Cos\ \theta}{Area\ R^2adius}$$

$$= \frac{Intensity\ Cos\ \theta}{R^2adius}$$

$$= \frac{300\ candela\ \cdot\ (Cos\ 30^\circ)}{(2\ ft)^2}$$

$$= \frac{300\ candela\ (0.867)}{(2\ ft)^2}$$

$$= 64.95\ lumens/ft^2\ or\ foot\text{-}candles$$

7. How many luminaires should go into this warehouse where there are active fine conditions? What is the best arrangement of the luminaires?

Room Dimensions

144' long x 48' wide x 13' high

Luminaires:

-distribution pattern 17% up, 69% down, Category I
-lamps will be FT2T/12CW/HO
-lamps will work 18 hours/start
-ballast is certified by Ballast Manufacturers Association
-conditions in the warehouse are considered dirty
-luminaires will be cleaned every 24 months
-luminaire reflectance about 80%

Mounting and Reflectance Information:

-assume floor reflectance on 20%
-assume mounting is 2 1/2' from ceiling
-assume work plane is 2 1/2' from floor
-wall reflectance is 30%
-base ceiling reflectance is 80%
-assume no adjustment for floor cavity ratio is required

Given the information, the following computations are required:

a. *Required level of illumination for warehouse, active fine conditions, is 50 foot-candles. (Determined using Recommended Standards.)*

b. *Compute Room Cavity Radio*

$$RCR = \frac{10h}{\text{room width}} \times \text{Gaysunas ratio}$$

where h is room cavity height of 8 feet and Gaysunas ratio for room length to room width is equal to 2/3; i.e.,

$$\frac{\text{room length}}{\text{room width}} = 3.0$$

$$RCR = \frac{10 \times 8 \text{ ft}}{48 \text{ ft}} \times .66 = 1.09 \text{ (use 1.0)}$$

c. *Compute Ceiling Cavity Ratio*

$$CCR = \frac{10h}{\text{room width}} \times \text{Gaysunas ratio}$$

where h = 2 1/2' and Gaysunas ratio = 2/3

$$CCR = \frac{10(2.5) \text{ ft}}{48 \text{ ft}} \times .66$$

$$= 0.343$$

d. *Compute Effective Ceiling Reflectance (using chart) where base reflectance = 80% and wall reflectance = 30%.*

From Table

Cavity Ratio	80% Ceiling 30% Wall
.2	.76
.4	.72

Therefore, Effective Ceiling Reflectance is approximately 73% or 0.73.

e. *Look up Coefficient of Utilization*

RCR = 1.09 (use 1.0)
Effective Ceiling Reflectance = 73%
Category I (distribution of 17% to 69%)
Wall 30% reflectance

Table

	80%	70%
RCR 1	.79	.76

Therefore, at 73%, the coefficient is approximately 0.769.

f. *Compute Light Loss Factor*

a. *Ballast performance (given) = .95*
b. *Luminaire reflectance (given) = .80*
c. *Lamp lumen depreciation (18 hours) = .83 (from table)*
d. *Dirt depreciation = .79 (from curves)*

Light Loss Factor = .95 x .80 x .83 x .79 = 0.498

g. *Compute Number of Lamps*

$$\text{Number of Lamps} = \frac{\text{Foot-candles x Area}}{\text{Lumens per lamp x coefficient of utilization x light loss factor}}$$

$$= \frac{50 \times 144 \times 48}{\text{Lumens per lamp} \times .769 \times .498}$$

$$= \frac{50 \times 144 \times 48}{6450 \times .769 \times .498}$$ *(6450, lumens per lamp, from table of Lamp Data)*

$$= \frac{345600}{2470.11}$$

$$= 139.9 \sim 140$$

h. *Compute the Number of Luminaires*

$$\text{Number of Luminaires} = \frac{\text{Number of lamps}}{\text{Lamps/luminaire}}$$

$$= \frac{140}{2}$$

$$= 70$$

i. *Arrangement*

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