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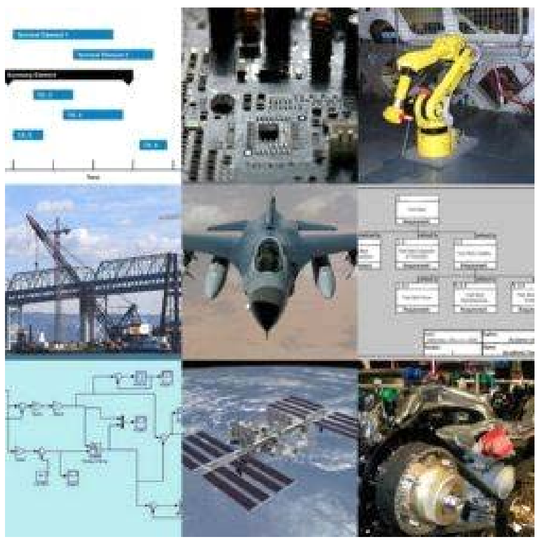

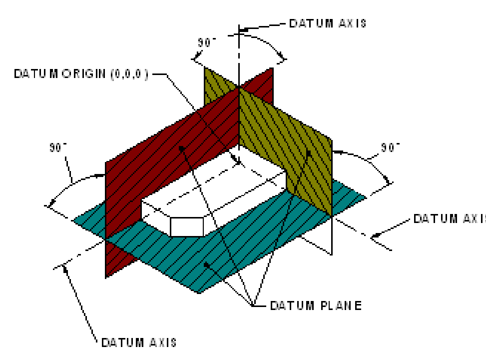

Introduction to Solar Energy

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COURSE CONTENT

1. Introduction

Solar energy travels from the sun to the earth in the form of electromagnetic radiation. In this course properties of electromagnetic radiation will be discussed and basic calculations for electromagnetic radiation will be described. Several solar position parameters will be discussed along with means of calculating values for them. The major methods by which solar radiation is converted into other useable forms of energy will be discussed briefly. Extraterrestrial solar radiation (that striking the earth's outer atmosphere) will be discussed and means of estimating its value at a given location and time will be presented. Finally there will be a presentation of how to obtain values for the average monthly rate of solar radiation striking the surface of a typical solar collector, at a specified location in the United States for a given month. Numerous examples are included to illustrate the calculations and data retrieval methods presented.

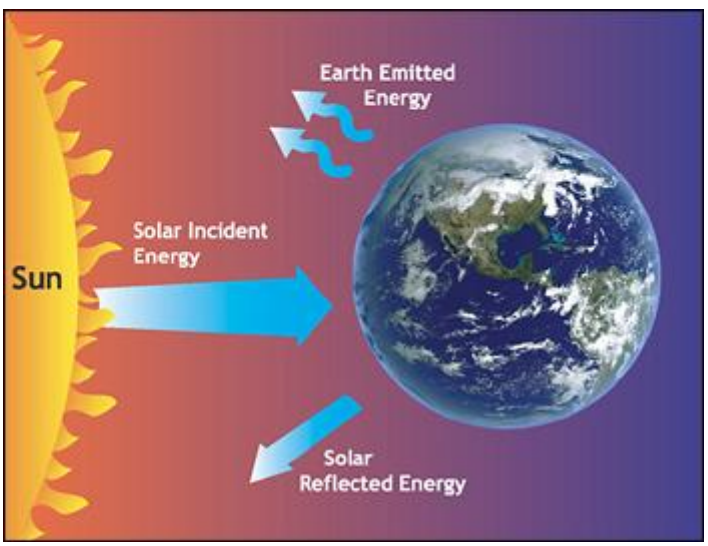

Image Credit: NOAA, Earth System Research Laboratory

2. Learning Objectives

At the conclusion of this course, the student will

- Know the different types of electromagnetic radiation and which of them are included in solar radiation.
- Be able to calculate wavelength if given frequency for specified electromagnetic radiation.
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- Know the meaning of absorbance, reflectance and transmittance as applied to a surface receiving electromagnetic radiation and be able to make calculations with those parameters.
- Be able to obtain or calculate values for solar declination, solar hour angle, solar altitude angle, sunrise angle, and sunset angle.
- Be able to use solar declination, solar hour angle, solar altitude angle, sunrise angle, and sunset angle values in calculations.
- Know the major methods by which solar radiation is converted into other useable forms of energy.
- Be able to obtain an estimated value for monthly averaged extraterrestrial radiation on a horizontal surface for a specified month and latitude between 20 and 65 degrees.
- Be able to obtain values for the average monthly rate of solar radiation striking the surface of a typical solar collector, at a specified location in the United States for a given month.

3. Outline of Topics

I. The Nature of Electromagnetic Radiation (Including Solar Radiation)

II. What Happens to Solar Radiation When It Strikes an Object

III. Solar Position Parameters and Calculation of Their Value

a. Solar Declination
b. Solar Hour Angle
c. Solar Altitude Angle
d. Sunrise Hour Angle
e. Sunset Hour Angle

IV. Methods of Utilizing Solar Energy

a. Solar Space Heating
b. Solar Water Heating
c. Solar Generation of Electricity

V. Extraterrestrial Solar Radiation

VI. Terrestrial Solar Radiation Quantities or Rates

Information from: *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*

a. Station Description
b. Flat-Plate Collector Facing South at a Fixed Tilt
c. One-Axis Tracking Flat-Plate Collectors with Axis Oriented North-South
d. Two-Axis Tracking Flat Plate Collectors
e. Concentrating Collectors
f. Solar Radiation Graph
g. Climate Conditions

VII. Summary

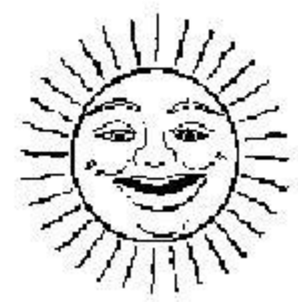
VIII. References

4. The Nature of Electromagnetic Radiation (Including Solar Radiation)

There are many forms of electromagnetic radiation, such as radio waves, infrared radiation (heat), visible light, ultraviolet light, x-rays, and gamma rays. These different forms of electromagnetic radiation are all characterized by their wavelength, λ, and frequency, μ . All electromagnetic radiation travels at the speed of light, c, so the product of wavelength and frequency for any type of electromagnetic radiation equals the speed of light. That is:

$$\lambda\mu = c \qquad (1)$$

Thus long wavelength electromagnetic radiation has a low frequency and short wavelength electromagnetic radiation has a high frequency. The different types of electromagnetic radiation listed above are arranged from lowest frequency (radio waves) to highest frequency (gamma waves).



The speed of light in a vacuum is 3.000×10^8 m/sec. Thus, if the wavelength of a particular type of electromagnetic radiation is known, its frequency can be calculated and vice versa using equation (1).

Example #1: What will be the wavelength of a radio wave with a frequency of 200,000 cycles per second?

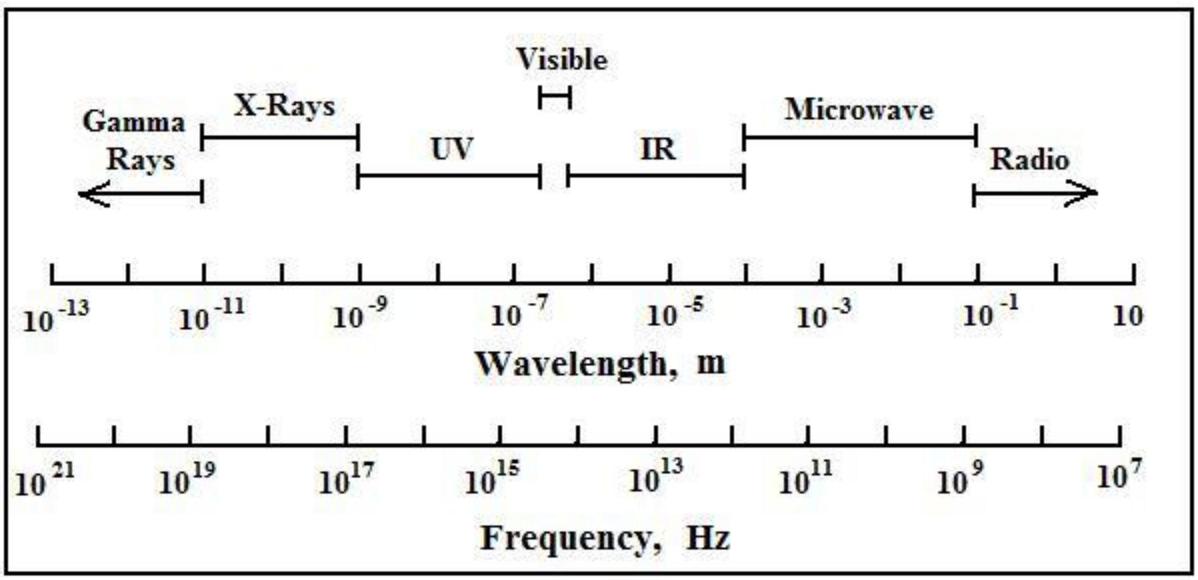
Solution: The wavelength can be calculated from equation (1):

$$\lambda = c/\mu = (3 \times 10^8 \text{ m/sec})/(2 \times 10^5 \text{ cycles/sec}) = 1500 \text{ m/cycle}$$

or, as usually expressed, simply: **1500 m**

Figure 1 summarizes the electromagnetic radiation spectrum. It shows the various forms of electromagnetic radiation and the range of wavelength and frequency of each.

Figure 1. Summary of the Electromagnetic Spectrum



Solar radiation has most of its energy between wavelengths of 10^{-7} and 3×10^{-6} m. This includes ultraviolet light, visible light and infrared radiation. Visible light and near-infrared (wavelength of 7×10^{-7} to 4×10^{-7} m) make up over 90% of the solar radiation reaching the Earth's atmosphere. Less than 10% of solar radiation is ultraviolet (uv) light (wavelength of 10^{-9} to 4×10^{-7} m). This is illustrated in Figure 2 below.

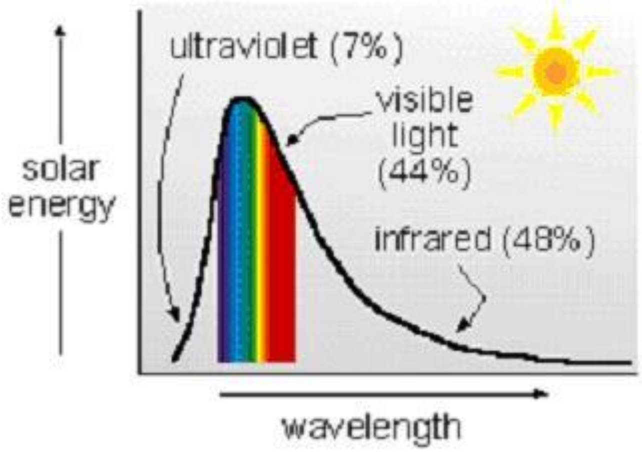
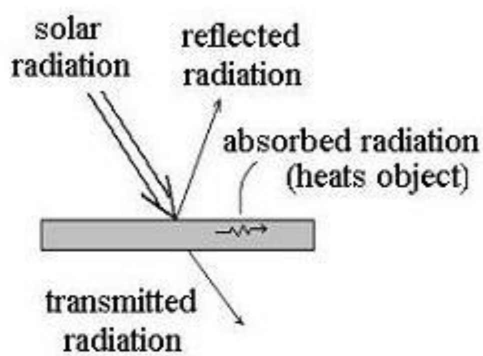


Figure 2. Approximate characteristics of solar radiation reaching the Earth

5. What Happens to Solar Radiation when it Strikes an Object ?



When solar radiation strikes any object, one or more of three things must happen to it. The radiation will be absorbed, reflected, and/or transmitted through the object depending upon the nature of the surface. If the object is smooth and shiny like a mirror, then most of the radiation will be reflected. If the surface has a dark-colored, dull, matte finish, then almost all of the radiation will be absorbed, thus heating the object. If the surface is transparent or transluscent to electromagnetic radiation of the wavelength striking it, then it will be completely or partially transmitted through and continue until it strikes something else. The reflected fraction of incident radiation is called the reflectance, r. The absorbed fraction is called the absorbance, a, and the transmitted fraction is called the transmittance, t. All the incident radiation must be accounted for by the sum of these three fractions, thus:

$$a + r + t = 1 \qquad (2)$$

An object which al... pass through it is s... Solar radiation, wh... will then travel on ... ultimately absorbe...

Example #2: A tr... striking it and has ... striking a sheet of ... sheet.

Solution: The refl... rate of reflected ra... Kilowatts = **0.105 ...**

6. Solar Positio...

hour angle will be discussed in this section.

Solar declination is the angle between the sun's rays and a plane passing through the equator. This is illustrated in Figure 3. The solar declination depends only on the day of the year. The declination is also equal to the latitude at which the sun is directly overhead at solar noon on the given day. The declination is positive when the sun is directly overhead north of the equator (December 21 through June 21) and it is negative when the sun is