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This advisory circular (AC) was published by the Federal Aviation Administration (FAA) Flight Standards Service (AFS), with contributions from the National Weather Service (NWS). The publication began in 1943 as CAA Bulletin No. 25, Meteorology for Pilots, which at the time contained weather knowledge considered essential for most pilots. As aircraft flew farther, faster, and higher, and as meteorological knowledge grew, the bulletin became obsolete. It was revised in 1954 under a new title, The Pilots' Weather Handbook, and updated again in 1965. In 1975 it was revised under its current title.

Previous editions have suffered one common problem—they dealt in part with weather services that continually change, in keeping with current techniques and service demands. As a result, each edition was somewhat outdated almost as soon as it was published, its obsolescence growing throughout the period it remained in print.

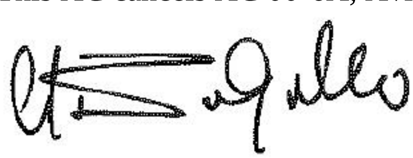
In 1975, in order to alleviate this problem, the authors completely rewrote the AC. They streamlined it into a clear, concise, readable book, and omitted all reference to specific weather services.

The 1975 text remained valid and adequate for many years. Its companion manual, the current edition of AC 00-45, Aviation Weather Services, supplements this AC. In 2015, this supplement was updated concurrently with this text. This was done to reflect changes brought about by new products and services, particularly since this information is now available through the Internet. The companion AC describes current weather services and formats, and uses real world examples of weather graphics and text products.

The two manuals can be downloaded for free via the Internet in PDF format. Print versions are also sold separately at nominal cost, allowing pilots the opportunity to own a reference copy of the supplement to keep current with aviation weather services.

New scientific capabilities now necessitate an update to this AC. In 1975, aviation users were not directly touched by radar and satellite weather. In 2016, much of what airmen understand about the current atmosphere comes from these important data sources. This AC is intended to provide basic weather information that all airmen must know. This document is intended to be used as a resource for pilot and dispatcher training programs.

This AC cancels AC 00-6A, Aviation Weather for Pilots and Flight Operations Personnel.



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CHAPTER 1. THE EARTH'S ATMOSPHERE

1.1 Introduction. The Earth's atmosphere is a cloud of gas and suspended solids extending from the surface out many thousands of miles, becoming increasingly thinner with distance, but always held by the Earth's gravitational pull. The atmosphere is made up of layers surrounding the Earth that holds the air we breathe, protects us from outer space, and holds moisture (e.g., vapor, clouds, and precipitation), gases, and tiny particles. In short, the atmosphere is the protective bubble we live in.

This chapter covers our atmosphere's composition, vertical structure and the standard atmosphere.

1.2 Composition. The Earth's atmosphere consists of numerous gases (see Table 1-1) with the top four making up 99.998 percent of all gases. Nitrogen, by far the most common, dilutes oxygen and prevents rapid burning at the Earth's surface. Living things need it to make proteins. Oxygen is used by all living things and is essential for respiration. Plants use carbon dioxide to make oxygen. Carbon dioxide also acts as a blanket and prevents the escape of heat to outer space.

Table 1-1. Composition of a Dry Earth's Atmosphere

Gas	Symbol	Content (by Volume)
Nitrogen	N_2	78.084%
Oxygen	O_2	20.947%
Argon	Ar	0.934%
Carbon Dioxide	CO_2	0.033%
Neon	Ne	18.20 parts per million
Helium	He	5.20 parts per million
Methane	CH_4	1.75 parts per million
Krypton	Kr	1.10 parts per million
Sulfur dioxide	SO_2	1.00 parts per million
Hydrogen	H_2	0.50 parts per million
Nitrous Oxide	N_2O	0.50 parts per million
Xenon	Xe	0.09 parts per million

Gas	Symbol	Content (by Volume)
Ozone	O_3	0.07 parts per million
Nitrogen dioxide	NO_2	0.02 parts per million
Iodine	I_2	0.01 parts per million
Carbon monoxide	CO	trace
Ammonia	NH_3	trace
Note: *The atmosphere always contains some water vapor in amounts varying from trace to about four percent by volume. As water vapor content increases, the other gases decrease proportionately.*		

Weather, the state of the atmosphere at any given time and place, strongly influences our daily routine as well as our general life patterns. Virtually all of our activities are affected by weather, but, of all our endeavors, perhaps none more so than aviation.

1.2.1 Air Parcel. An air parcel is an imaginary volume of air to which any or all of the basic properties of atmospheric air may be assigned. A parcel is large enough to contain a very large number of molecules, but small enough so that the properties assigned to it are approximately uniform. It is not given precise numerical definition, but a cubic centimeter of air might fit well into most contexts where air parcels are discussed. In meteorology, an air parcel is used as a tool to describe certain atmospheric processes, and we will refer to air parcels throughout this document.

1.3 **Vertical Structure.** The Earth's atmosphere is subdivided into five concentric layers (see Figure 1-1) based on the vertical profile of average air temperature changes, chemical composition, movement, and density. Each of the five layers is topped by a pause, where the maximum changes in thermal characteristics, chemical composition, movement, and density occur.

1.3.1 Troposphere. The troposphere begins at the Earth's surface and extends up to about 11 kilometers (36,000 feet) high. This is where we live. As the gases in this layer decrease with height, the air becomes thinner. Therefore, the temperature in the troposphere also decreases with height. As you climb higher, the temperature drops from about 15 °C (59 °F) to -56.5 °C (-70 °F). Almost all weather occurs in this region.

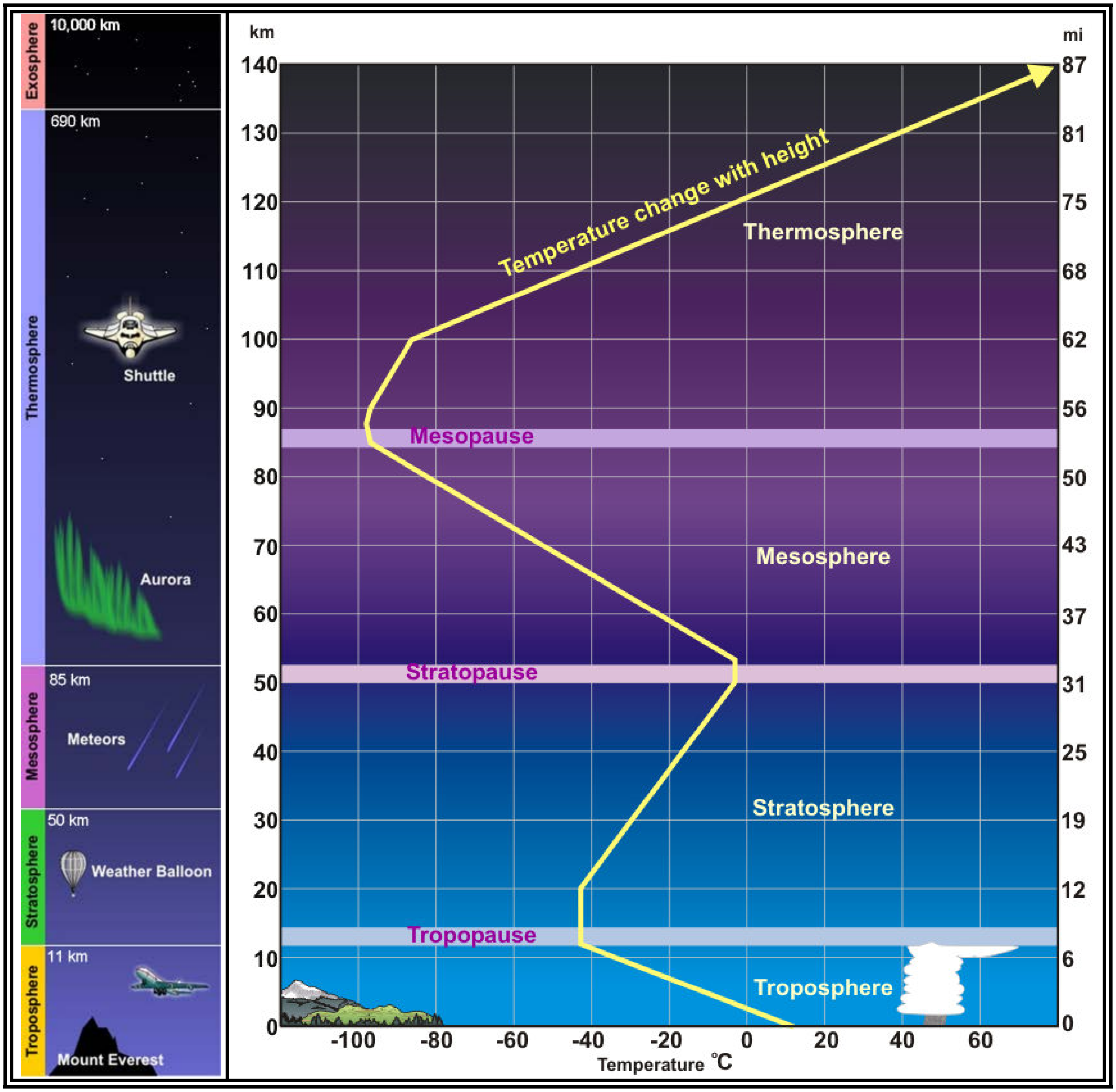
The vertical depth of the troposphere varies due to temperature variations which are closely associated with latitude and season. It decreases from the Equator to the poles, and is higher during summer than in winter. At the Equator, it is around 18-20 kilometers (11-12 miles) high, at 50° N and 50° S latitude, 9 kilometers (5.6 miles), and at the poles, 6 kilometers (3.7 miles) high. The transition boundary between the troposphere and the layer above is called the tropopause. Both the tropopause and the troposphere are known as the lower atmosphere.

1.3.2 Stratosphere. The stratosphere extends from the tropopause up to 50 kilometers (31 miles) above the Earth's surface. This layer holds 19 percent of the atmosphere's gases, but very little water vapor.

Temperature increases with height as radiation is increasingly absorbed by oxygen molecules, leading to the formation of ozone. The temperature rises from an average -56.6 °C (-70 °F) at the tropopause to a maximum of about -3 °C (27 °F) at the stratopause due to this absorption of ultraviolet radiation. The increasing temperature also makes it a calm layer, with movements of the gases being slow.

Commercial aircraft often cruise in the lower stratosphere to avoid atmospheric turbulence and convection in the troposphere. Severe turbulence during the cruise phase of flight can be caused by the convective overshoot of thunderstorms from the troposphere below. The disadvantages of flying in the stratosphere can include increased fuel consumption due to warmer temperatures, increased levels of radiation, and increased concentration of ozone.

Figure 1-1. Vertical Structure of the Atmosphere



The regions of the stratosphere and the mesosphere, along with the stratopause and mesopause, are called the middle atmosphere. The transition boundary that separates the stratosphere from the mesosphere is called the stratopause.

1.3.3 Mesosphere. The mesosphere extends from the stratopause to about 85 kilometers (53 miles) above the Earth. The gases, including the number of oxygen molecules, continue to become thinner and thinner with height. As such, the effect of the warming by ultraviolet radiation also becomes less and less pronounced, leading to a decrease in temperature with height. On average, temperature decreases from about -3 °C (27 °F) to as low as -100 °C (-148 °F) at the mesopause. However, the gases in the mesosphere are thick enough to slow down meteorites hurtling into the atmosphere where they burn up, leaving fiery trails in the night sky.

1.3.4 Thermosphere. The thermosphere extends from the mesopause to 690 kilometers (430 miles) above the Earth. This layer is known as the upper atmosphere.

The gases of the thermosphere become increasingly thin compared to the mesosphere. As such, only the higher energy ultraviolet and x ray radiation from the sun is absorbed. But because of this absorption, the temperature increases with height and can reach as high as 2,000 °C (3,600 °F) near the top of this layer.

Despite the high temperature, this layer of the atmosphere would still feel very cold to our skin, because of the extremely thin air. The total amount of energy from the very few molecules in this layer is not sufficient enough to heat our skin.

1.3.5 Exosphere. The exosphere is the outermost layer of the atmosphere, and extends from the thermopause to 10,000 kilometers (6,200 miles) above the Earth. In this layer, atoms and molecules escape into space and satellites orbit the Earth. The transition boundary that separates the exosphere from the thermosphere is called the thermopause.

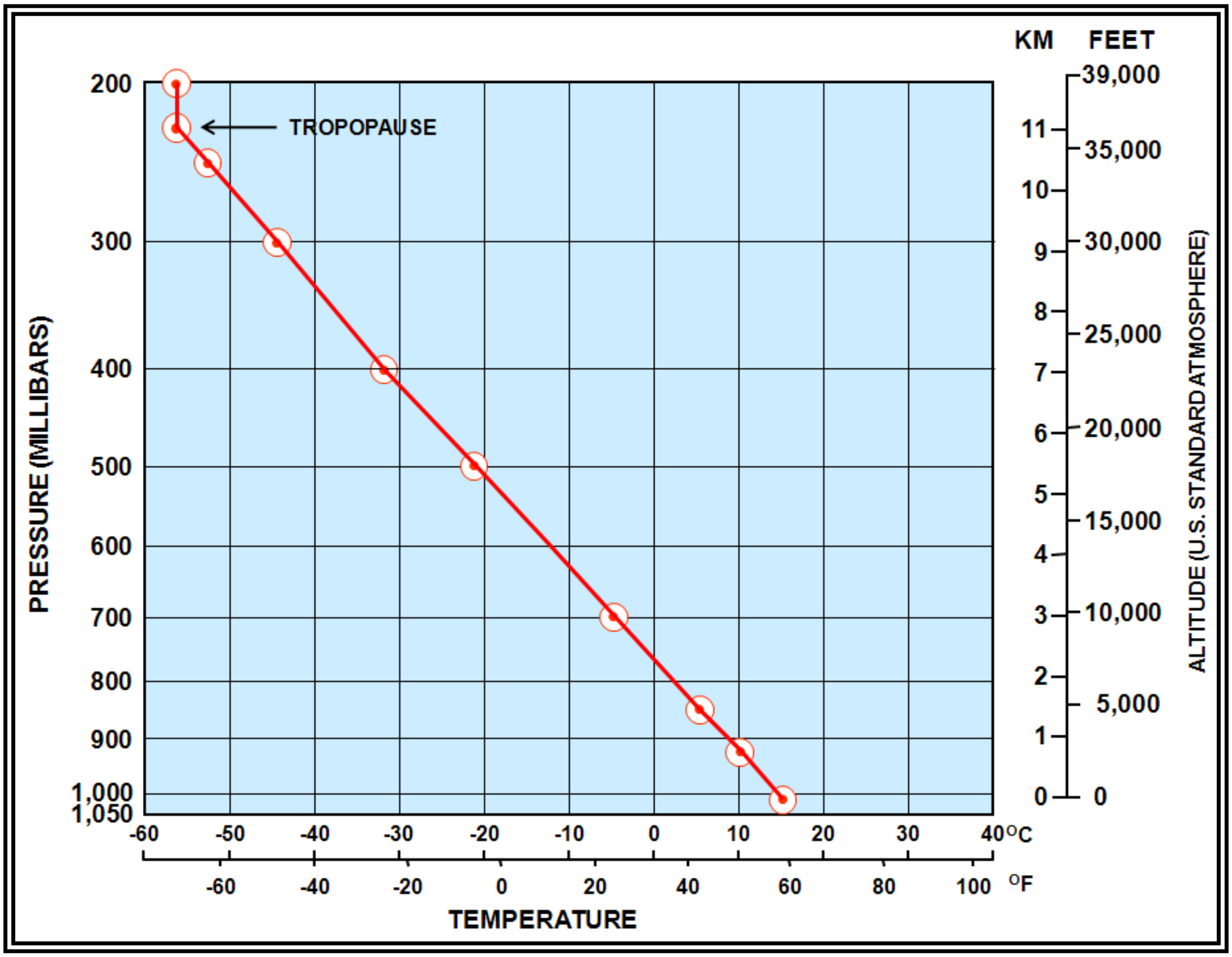
1.4 **The Standard Atmosphere.** Continuous fluctuations of atmospheric properties create problems for engineers and meteorologists who require a fixed standard for reference. To solve this problem, they defined a standard atmosphere, which represents an average of conditions throughout the atmosphere for all latitudes, seasons, and altitudes.

Standard atmosphere is a hypothetical vertical distribution of atmospheric temperature, pressure, and density that, by international agreement, is taken to be representative of the atmosphere for purposes of pressure altimeter calibrations, aircraft performance calculations, aircraft and missile design, ballistic tables, etc. (see Table 1-2 and Figure 1-2). Weather-related processes are generally referenced to the standard atmosphere, as are examples in this document.

Table 1-2. Selected Properties of the Standard Atmosphere

Property	Metric Units	English Units
Sea level pressure	1013.25 hectopascals	29.92 inches of mercury
Sea level temperature	15 °C	59 °F
Lapse rate of temperature in the troposphere	6.5 °C/1,000 meters	3.57 °F/1,000 feet
Pressure altitude of the tropopause	11,000 meters	36,089 feet
Temperature at the tropopause	-56.5 °C	-69.7 °F
Note: *1 hectopascal = 1 millibar.*		

Figure 1-2. U.S. Standard Atmosphere within the Troposphere



CHAPTER 2. HEAT AND TEMPERATURE

2.1 Introduction. Temperature is one of the most basic variables used to describe the state of the atmosphere. We know that air temperature varies with time from one season to the next, between day and night, and even from one hour to the next. Air temperature also varies from one location to another, from high altitudes and latitudes to low altitudes and latitudes. Temperature can be critical to some flight operations. As a foundation for the study of temperature effects on aviation and weather, this chapter describes temperature, temperature measurement, and heat transfer and imbalances.

2.2 Matter. Matter is the substance of which all physical objects are composed. Matter is composed of atoms and molecules, both of which occupy space and have mass. The Earth's gravity acting on the mass of matter produces weight.

2.3 Energy. Energy is the ability to do work. It can exist in many forms and can be converted from one form to another. For example, if a ball is located at the edge of a slide, it contains some amount of potential energy (energy of position). This potential energy is converted to kinetic energy (energy of motion) when the ball rolls down the slide. Atoms and molecules produce kinetic energy because they are in constant motion. Higher speeds of motion indicate higher levels of kinetic energy.

2.4 Heat. Heat is the total kinetic energy of the atoms and molecules composing a substance. The atoms and molecules in a substance do not all move at the same velocity. Thus, there is actually a range of kinetic energy among the atoms and molecules.

2.5 Temperature. Temperature is a numerical value representing the average kinetic energy of the atoms and molecules within matter. Temperature depends directly on the energy of molecular motion. Higher (warmer) temperatures indicate a higher average kinetic energy of molecular motion due to faster molecular speeds. Lower (colder) temperatures indicate a lower average kinetic energy of molecular motion due to slower molecular speeds. Temperature is an indicator of the internal energy of air.

2.5.1 Temperature Measurement. A thermometer is an instrument used to measure temperature. Higher temperatures correspond to higher molecular energies, while lower temperatures correspond to lower molecular energies.

2.5.2 Temperature Scales. Many scientists use the Kelvin (K) scale, which is a thermodynamic (absolute) temperature scale, where absolute zero, the theoretical absence of all thermal energy, is zero Kelvin (0 K). Thus, the Kelvin scale is a direct measure of the average kinetic molecular activity. Because nothing can be colder than absolute zero, the Kelvin scale contains no negative numbers.

The Celsius (°C) scale is the most commonly used temperature scale worldwide and in meteorology. The scale is approximately based on the freezing point (0 °C) and boiling point of water (100 °C) under a pressure of one standard atmosphere (approximately sea level). Each degree on the Celsius scale is exactly the same size as a degree on the Kelvin scale.

Table 2-1. Celsius Temperature Conversion Formulae

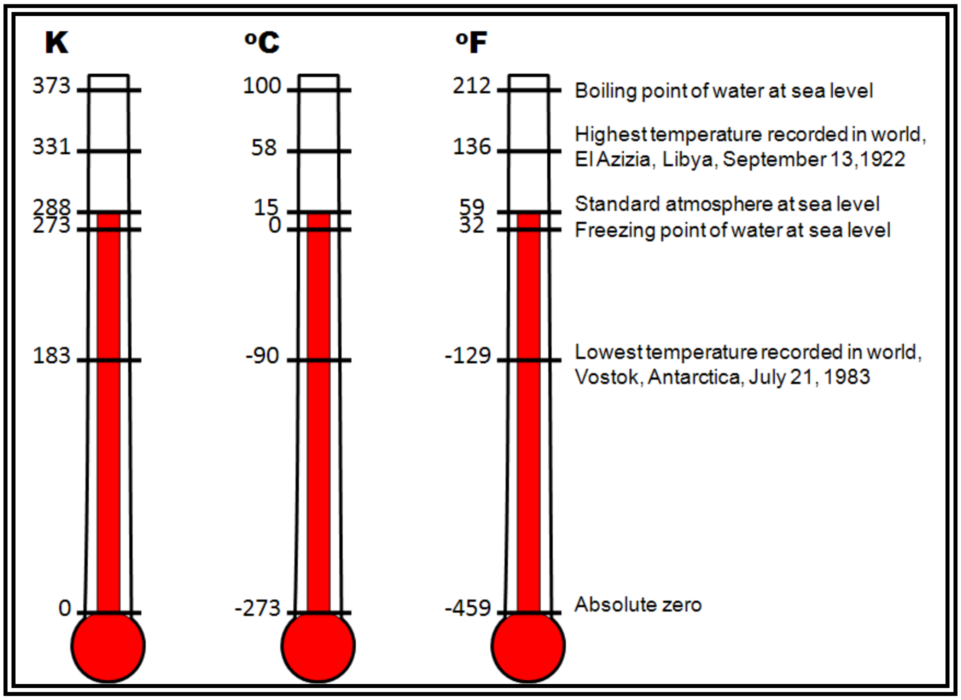
	From Celsius	To Celsius
Fahrenheit	[°F] = ([°C] x 9/5) + 32	[°C] = ([°F] – 32) x 5/9
Kelvin	[K] = [°C] + 273.15	[°C] = [K] – 273.15
For temperature *intervals* rather than specific temperatures, 1 °C = 274.15 K and 1 °C = 33.8 °F		

The United States uses Fahrenheit (°F) scale for everyday temperature measurements. In this scale, the freezing point of water is 32 degrees Fahrenheit (32 °F) and the boiling point is 212 degrees Fahrenheit (212 °F).

Table 2-2. Fahrenheit Temperature Conversion Formulae

	From Fahrenheit	To Fahrenheit
Celsius	[°C] = ([°F] – 32) x 5/9	[°F] = ([°C] x 9/5) + 32
Kelvin	[K] = ([°F] + 459.67) x 5/9	[°F] = ([K] x 9/5) – 459.67
For temperature *intervals* rather than specific temperatures, 1 °F = 255.93 K and 1 °F = -17.22 °C		

Figure 2-1. Comparison of Kelvin, Celsius, and Fahrenheit Temperature Scales



A thermometer changes readings due to the addition or subtraction of heat. Heat and temperature are not the same, but they are related.

2.6 Heat Transfer. Heat transfer is energy transfer as a consequence of temperature difference. When a physical body (e.g., an object or fluid) is at a different temperature than its surroundings or another body, transfer of thermal energy, also known as heat transfer (or heat exchange) occurs in such a way that the body and the surroundings reach thermal equilibrium (balance). Heat transfer always occurs from a hot body to a cold body. Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped; it can only be slowed down.

The heat source for the surface of our planet is the sun. Energy from the sun is transferred through space and through the Earth's atmosphere to the Earth's surface. Since this energy warms the surface and atmosphere, some of it becomes heat energy. There are three ways heat is transferred into and through the atmosphere: radiation, conduction, convection, or any combination of these. Heat transfer associated with the heat change of water from one phase to another (i.e., liquid water releases heat when changed to a vapor, liquid water absorbs heat when it changes to ice) can be fundamentally treated as a variation of convective heat transfer. The heat transfer associated with water will be discussed later.

2.6.1 Radiation. If you have stood in front of a fireplace or near a campfire, you have felt the heat transfer known as radiation. The side of your body nearest the fire warms, while your other side remains unaffected by the heat. Although you are surrounded by air, the air has nothing to do with this type of heat transfer. Heat lamps that keep food warm work in the same way.

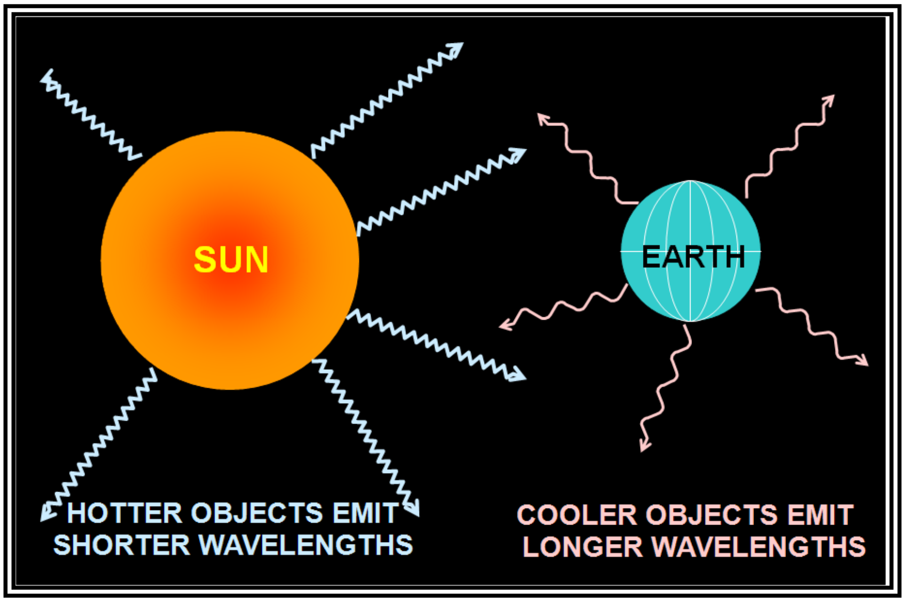
Radiation is the transfer of heat energy through space by electromagnetic radiation. These electromagnetic waves travel at the speed of light and are usually described in terms of wavelength or frequency. Frequencies range from gamma rays on the high end to radio waves on the low end. Also contained in the spectrum are x ray, ultraviolet, visible, infrared, and microwave.

Figure 2-2. Radiation Example

All objects emit (radiate) energy as the heat energy within the object is converted to radiation energy. This transmitted radiation passes through entities such as air, water, or space. Along the way, the radiation can be reflected, which occurs when the wave energy changes direction when encountering an object. Eventually, the radiation is absorbed and the electromagnetic wave energy is converted to heat energy by the absorbing object. The emitting object loses heat energy, and the absorbing object gains heat energy during this process.

2.6.1.1 Solar and Terrestrial Radiation. All objects emit radiation energy, including the sun (solar radiation) and the Earth (terrestrial radiation). An object's wavelength of maximum radiation is inversely related to its temperature; the hotter (colder) the object, the shorter (longer) the wavelength. The sun's wavelength of maximum radiation is relatively short and is centered in the visible spectrum. The Earth's wavelength of maximum radiation is relatively long and is centered in the infrared spectrum.

Figure 2-3. Temperature's Effect on Radiation Wavelength

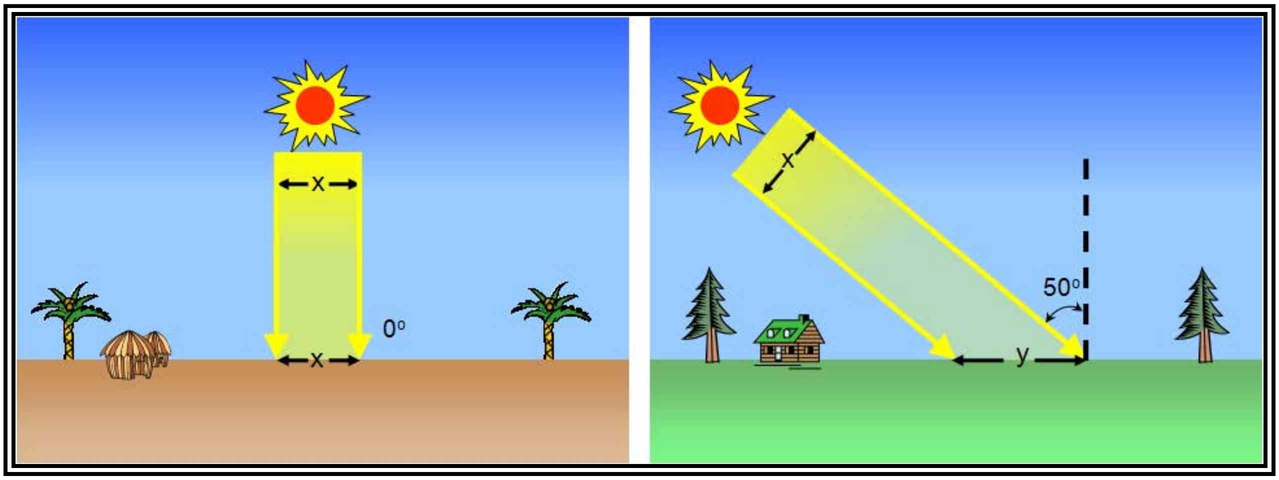


Some of the solar radiation that reaches the Earth's surface is radiated back into the atmosphere to become heat energy. Dark-colored objects such as asphalt absorb more of the radiant energy and warm faster than light-colored objects. Dark objects also radiate their energy faster than light-colored objects.

2.6.1.2 Solar Zenith Angle. The intensity of incoming solar radiation that strikes the Earth's surface (insolation) varies with solar zenith angle. Solar zenith angle is the angle measured from the Earth's surface between the sun and the zenith (i.e., directly overhead). Solar zenith angle varies with latitude, season, and the diurnal cycle (sunrise/sunset).

Figure 2-4 illustrates the concept. Insolation is maximized when the solar zenith angle is zero degrees (0°), which means the sun is directly overhead. With increasing solar zenith angle, the insolation is spread over an increasingly larger surface area (y is greater than x) so that the insolation becomes less intense. Also, with increasing solar zenith angle, the sun's rays must pass through more of the Earth's atmosphere, where they can be scattered and absorbed before reaching the Earth's surface. Thus, the sun can heat the surface to a much higher temperature when it is high in the sky, rather than low on the horizon.

Figure 2-4. Solar Zenith Angle



2.6.2 Conduction. Conduction is the transfer of energy (including heat) by molecular activity from one substance to another in contact, or through, a substance. Heat always flows from the warmer substance to the colder substance. The rate of heat transfer is greater with larger temperature differences and depends directly on the ability of the substance(s) to conduct heat. During conduction, the warmer substance cools and loses heat energy, while the cooler substance warms and gains heat energy.

Heat (thermal) conductivity is the property of a substance that indicates its ability to conduct heat as a consequence of molecular motion. Units are Watts per meter-Kelvin ($W\ m^{-1}\ K^{-1}$). Table 2-3 below provides the heat (thermal) conductivity of various substances. Note that air is a poor thermal conductor.