Heat and Temperature
A. **Heat**

1. A form of **energy**.
HEAT:

2. The *total* **kinetic energy** of all the atoms and molecules of a substance.
3. Heat always moves from a **higher** temperature body to a **lower** temperature body.
B. **Temperature**

1. The **average kinetic energy** of the **individual** atoms or molecules in a substance

2. Addition of heat energy causes atoms to **move faster** and removal causes atoms to **slow** down.
3. The total amount of heat of a substance depends upon its **mass**.

- For example, a substance can have a *high temperature* and *small amount* of heat while another may contain a *large amount of heat* and have a *low temperature*. 
4. **calories**

a. A unit for measuring the quantity of heat when an object is heated or cools off.

b. Defined as the quantity of heat needed to **raise the temperature of one gram of water** one degree Celsius.

c. This is the older unit but is usually used for water.

d. The newer unit is the Joule (1 calorie = 4.18 Joules)
Don’t confuse the calorie with the Calorie

- The Calorie is used for food and is actually a kilocalorie (1000 calories).
Why is the ocean water still warm in November?
5. **Specific Heat**

a. Defined as the quantity of heat needed to raise the temperature of [any substance](#) by one degree Celsius.

b. The [higher](#) the specific heat of a substance, the [greater](#) the amount of heat needed to raise its temperature.

i. Water has the [highest](#) specific heat of all natural substances (4.18 Joules/gram °C which is 1.0 calories/gram °C)

ii. By comparison the only 0.84 joules are required to heat one gram of the rock basalt one degree Celsius (basalt has a specific heat of 0.84 Joules/gram °C)
iii. Specific heats of some common natural substances are listed in the *Earth Science Reference Tables*.

![Specific Heats of Common Materials Table](image)

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>SPECIFIC HEAT (Joules/gram • °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid water</td>
<td>4.18</td>
</tr>
<tr>
<td>Solid water (ice)</td>
<td>2.11</td>
</tr>
<tr>
<td>Water vapor</td>
<td>2.00</td>
</tr>
<tr>
<td>Dry air</td>
<td>1.01</td>
</tr>
<tr>
<td>Basalt</td>
<td>0.84</td>
</tr>
<tr>
<td>Granite</td>
<td>0.79</td>
</tr>
<tr>
<td>Iron</td>
<td>0.45</td>
</tr>
<tr>
<td>Copper</td>
<td>0.38</td>
</tr>
<tr>
<td>Lead</td>
<td>0.13</td>
</tr>
</tbody>
</table>
6. **Heat Loss or Gain** can be expressed by the following equation.

\[
Q = m \Delta T C_p
\]

- **Q** = total heat lost or gained
- **m** = mass in grams
- **\(\Delta T\)** = change in temperature of the substance
- **\(C_p\)** = specific heat of the substance
Sample Problem 1
(not in notes, I will give out a worksheet)

• How much heat is needed to raise the temperature of 10 grams of **basalt** from 30° C to 50° C?

• \[ Q = m \Delta T C_p \]
  
  \[ = 10 \text{ g} \times 20^\circ \text{C} \times 0.84 \text{ Joules/gram} \cdot ^\circ \text{C} \]
  
  \[ = 168 \text{ Joules} \]
Sample Problem 2

• How much heat is needed to raise the temperature of 10 grams of \textit{water} from 30^\circ\text{C} to 50^\circ\text{C}?

\[ Q = m \Delta T C_p \]
\[ = 10 \text{ g} \times 20^\circ\text{C} \times 4.18 \text{ Joules/gram} \cdot ^\circ\text{C} \]
\[ = 836.0 \text{ Joules} \]
How does Specific Heat affect these lab results?
Coastal and Continental Temperature Ranges Lab 7-3

Comparison of Annual Temperature Range

Coastal (Los Angeles, CA)

Continental (Phoenix, AZ)
C. Methods of Heat Transfer

1. Conduction
   a. The transfer of heat through electron and molecular ___________ from one molecule to another.

   b. Conduction is important only between Earth’s ____________ and the air immediately in ____________ with the surface.

   c. As a means of heat transfer for the atmosphere as a whole, conduction is the least significant and can be disregarded when considering most meteorological phenomena.
2. **Convection**

a. Heat transfer that involves **movement** or **circulation** of a substance.

b. Takes place in **fluids** where the material is able to flow.
c. **Convective Circulation**

i. Takes place when the fluid near the bottom is heated and becomes **less** dense.

ii. It rises, cools near the top and continues to “turn over.”

iii. **Thermals**: Air moves vertically in the atmosphere. Less dense air rises and transports heat to greater heights.
3. **Radiation**

a. The heat-transfer mechanism by which ____solar____ energy reaches Earth.

b. Doesn’t require a medium in which to travel and can pass through the ____vacuum of____ space.

c. The Sun emits ____light____ and ____heat____ along with the rest of electromagnetic spectrum of radiation.
II. **Insolation** *(Incoming Solar Radiation)*

A. **Radiation**: 

1. Travels out in all directions from the Sun and does travel through the ________ of space.
2. Heat transfer mechanism for ________ energy.
3. The Sun emits **all** wavelengths.

a. Most is concentrated in the **visible and near-visible range** (43%)
   
   See Rev. Book *Figure 8-1*, page 382.

b. Infrared to visible represents 49%

c. **Ultraviolet** represents 7%.
2. **Laws of Radiation**

a) **All** objects, at whatever temperature, emit radiant energy.

b) Hotter objects radiate **more total** energy per unit area than colder objects.

c) The hotter the radiating body, the **shorter** the wavelength of maximum radiation.

d) Objects that are good absorbers of radiation are also **good emitters of radiation**.

i) A **blackbody** is considered a perfect absorber and emitter. Earth’s surface approaches being a blackbody because it absorbs and radiates with nearly 100 percent efficiency.
ii. **Surface characteristics affect absorption and emission**

(1) **Color**

Darker colors absorb and radiate more heat than lighter colors.
Temperature Vs. Color

![Graph showing temperature vs. time for Black and White objects.](image)
The greater the reflection, the less heat that is absorbed.
(3) **Texture**

Rougher surfaces absorb more energy due to greater surface area.
B. **Intensity of Insolation**

1. This is the ___rate___ at which solar energy is received by a _given area_ of Earth’s surface per unit of ___time___ (usually calories/second/square centimeter).

   **Note:** Atmospheric scientists will use calories instead of Joules.
2. **Angle of Insolation**: The angle at which the Sun’s rays strike Earth’s surface

   a. **Direct** Rays strike the surface at right angles. They are ______ vertical.

   b. As the angle decreases, the rays become **less** direct and insolation is spread out over a **greater** area.

   c. Therefore, the **more direct the rays** striking Earth’s surface, the **greater** the intensity of insolation.
3. Factors Affection Angle of Insolation

a. Latitude

**Generally,** as latitude increases, angle of insolation decreases.
Latitudinal Variation of the Radiation Balance

Solar Radiation in Kcal/cm²
b. **Time of Day**

- The sun is highest at *solar noon*.
- This is when the angle of insolation will be greatest.
- From sunrise to solar noon the angle of insolation increases.
- From solar noon to sunset the angle of insolation decreases.
c. **Season**

- The Sun’s maximum angle of insolation is on the summer solstice.
- The minimum angle of insolation is on the winter solstice.
III. The Seasons
A. **Terrestrial** Observations (Observed from Earth) See Rev. Book Figure 9-21 on page 468 and Rev. Book Table 9-3 on page 469.

1. Change in length of **daylight**.

2. Change in the sun’s **apparent path** across the sky
   a) Change in **sunrise** and **sunset** positions
   b) Change in **noontime** altitude (solar noon or “high” noon)
      i) Change in angle of **incidence** of Sun’s rays with Earth’s surface
      ii) Change in **thickness** of atmosphere through which the Sun’s rays pass
B. Causes of changing the Sun’s noontime altitude and diurnal path throughout the year
1. Earth’s **orientation** to the Sun continually changes as it **revolves** around the Sun.

2. Earth’s axis is inclined **23 \( \frac{1}{2}^\circ \)** from a line perpendicular to the plane of it’s orbit.

3. **Parallelism** of Earth’s axis:

   A. Earth’s axis always points in the **same direction** in space.

   B. The orientation of the axis is at any position in its orbit **always parallel** to any other position (See Review Book Figure 8-6, page 386).
C. Solstices and Equinoxes
1. **Summer Solstice (Northern Hemisphere)**

   a) Northern axis tilts **towards** the Sun
   
   b) Sun’s **direct rays** at **23 ½° N** latitude
Land of the Midnight Sun north of the Arctic Circle
Daylight on June 21st
2. **Winter Solstice (Northern Hemisphere)**

a) Northern axis tilts **away from** the Sun.

b) Sun’s **direct rays** at **$23\ 1/2^\circ \ S$** latitude.
3. **Equinoxes** (Autumnal and Spring which is also called the *vernal* equinox)

- a) **Midway** between the solstices
- b) Sun’s direct rays **are on the equator**
The Analemma

• If you could record the position of the sun in the sky at noon every day throughout the year, you would notice that the sun follows a figure-8 path.
The Shape of the Analemma

• The figure-8 pattern is distorted because of the elliptical shape of Earth’s orbit.
• If Earth’s orbit were perfectly circular, both loops of the figure-8 would be equal in size.
Using the Analemma

- Set the analemma curve upright, and it becomes a miniature almanac.
- The vertical coordinate of each point on it gives the sun's declination on a particular day of the year,
- The horizontal coordinate tells how much the sun is ahead of or behind clock time on that day.
Vertical Rays of the Sun
Finding the Noon Sun Angle (altitude)

Data:
Location: 40° N
Date December 22
Location of 90° sun: 23½° S

Calculations:
Step 1:
Distance in degrees between 23½° S and 40° N = 63½°

Step 2:
90
- 63½° = Noon sun angle at 40°
on December 22
IV. The Atmosphere and Insolation
A. **What Happens to Insolation?**

1. **Scattering**
   a. Insolation is redirected by gases and dust particles (*aerosols*) in the atmosphere.
   b. Produces **diffused** light.
      i. Degree of scattering depends on **the size** of particles or gas molecules.
      ii. When light is scattered by very small particles, primarily gas molecules, it is distributed in all directions but most is scattered in the forward direction. Light lost to space is said to be **backscattered**.
iii  **The blue color of the sky:**
Gas particles more readily scatter shorter wavelengths (blue and violet).

1. During midday blue light is seen because it is most readily scattered.
2. When the Sun is lower light travels a longer path.
3. **A reddish or orange** color seen because most blue and violet is scattered before reaching the observer.
2. Reflection

a. Approx. 30% of insolation is reflected back into space by the outer atmosphere.

b. **Albedo**: The fraction reflected by a surface.
   
i. Varies with characteristics of the surface.
   
ii. Varies with weather conditions and time of day and year.
Albedo

(more reflection = higher Albedo)

Albedo values (% reflected)

- Fresh snow: 80%–95%
- Forests: 10%–20%
- Crops, grasslands: 10%–25%
- Asphalt (black top): 5%–10%
- Concrete, dry: 17%–27%
- Water bodies: 10%–60% (varies with Sun altitude)
- Moon: 6%–8%
- Earth’s albedo (average): 31%
Average Snow Cover in Months
Why is albedo lower over tropical oceans than over high latitude oceans?

- Greater angle of insolation and less reflection
Why is the albedo higher in northern N. America than in northern Africa and Central Australia?

- Northern N. America is snow covered for part of the year.
B. Heating the Atmosphere

1. Gases are the most effective absorbers of radiation and heat the atmosphere.

2. The atmosphere is nearly transparent to incoming solar radiation. Direct solar energy is not an effective “heater” of Earth’s Atmosphere.

3. The only significant absorbers of insolation are:
   a. Water Vapor
   b. Oxygen: High energy, shortwave radiation
   c. Ozone: High energy, shortwave radiation in the Stratosphere

4. The atmosphere is a relatively efficient absorber of long-wave (infrared) radiation.
The Stratosphere’s Ozone Layer
Destruction of Ozone by CFC’s

The CFC Problem
1. CFCs are released and rise to the stratosphere.
2. Sunlight breaks down the CFCs, releasing atomic chlorine.
3. Atomic chlorine destroys the ozone.
4. Increased ultraviolet rays reach the Earth’s surface, raising the risk of skin cancer and other dangerous consequences.
1. Emitted in **long** wavelengths.
C. Terrestrial Radiation and Heating of the Atmosphere

1. Much of the incoming, short wavelength, solar radiation penetrates the atmosphere and heats Earth’s surface.

3. Greenhouse gases absorb outgoing, long wavelength, radiation and reradiate some of this energy Earthward, thus trapping heat in the lower atmosphere.

2. **Infrared** range terrestrial radiation heats the atmosphere. As a result, the atmosphere heats from the ground up.
3. **Normal Lapse Rate**: 6.5° C temperature decrease per 1000 meters of altitude. The farther from the source of heat (the ground), the cooler it gets.

4. Carbon dioxide and water vapor are principal absorbing gases, accounting for warmer temperatures in the lower troposphere.
D. **The Greenhouse Effect** (Referred to by some scientists as the *Atmosphere Effect*).

1. The transmission of **shortwave** solar radiation by the atmosphere coupled with the selective **wavelengths** of longer-wave terrestrial radiation, especially by **water vapor** and **carbon dioxide**, resulting in warming of the atmosphere.
“The Greenhouse Effect”

Glass = Atmospheric gases: 
\((H_2O, CO_2, CH_4)\)
Absorbs (traps) the heat IR.

Insolation (short-wave)

Infra-Red (IR) heat (long-wave)

everything heating up.....
2. **Effects of cloud cover:**

a) **Reradiates** absorbed terrestrial radiation to the surface.
b. Clear nights vs. cloudy nights

- Terrestrial radiation is absorbed and reradiated
- Temperatures do not decrease as much as on a clear night.
Effect of Clouds on the Daily Temperature Range

- **Cooler** temperatures during the day.
- **Warmer** temperatures at night.
- A **smaller** temperature range.
c. Low cloud cover in desert regions results in higher daily temperature ranges.
V. Earth’s Heat Budget

Lab 7-4
V. Earth’s Heat Budget

A. **Annual and Daily Balance of Incoming and Outgoing Radiation**

1. **Surplus**
   a. Insolation is **greater** than terrestrial radiation.
   b. Temperatures **increase**.
   c. The greater the surplus, the **greater** the rate of temperature increase.

2. **Deficit**
   a. Insolation is **less** than terrestrial radiation.
   b. Temperatures **decrease**.
   c. The greater the deficit, the **greater** the rate of temperature decrease.
3. Time-Lag between Maximum Insolation and Maximum Temp. and between Minimum Insolation and Minimum Temperature

- After maximum insolation in June, insolation decreases.
- Insolation is still greater than terrestrial radiation so temperatures continue to increase until radiative balance is reached.

- After minimum insolation in December, insolation increases.
- Insolation is still less than terrestrial radiation, so temperatures continue to decrease until radiative balance is reached.
Why is the hottest time of day after solar noon (why the lag time)?
Earth’s Heat Budget

Incoming Solar Radiation

+100 units

Outgoing radiation lost to space

−100 units

-30 units lost to space

-58 units emitted to space by the atmosphere

-12 units longwave radiation to which the atmosphere is transparent

+20 units absorbed by atmosphere and clouds

+7 units absorbed

+23 units released by condensation

+8 units absorbed

+50 units absorbed by Earth’s surface

-7 units by conduction and convection

-23 units lost by evaporation

-20 units lost by longwave radiation

114 units

94 units

Longwave energy exchange between Earth’s surface and the atmosphere

-50 units lost by Earth’s surface
Lab 7-2 Vocab.

- **Heat Equator:** The thermal equator is a belt encircling the Earth, defined by the set of locations having the highest mean annual temperature at each longitude around the globe.

- **Radiative Balance:** a condition in which an object is absorbing and radiating the same amount of heat energy. Temp. will be constant.
B. *Latitudinal Heat Balance* (Heat Equator)

2. Observations:
   - The Heat Equator moves higher in latitude over land.
   - In the N. Hemisphere summer it moves higher in latitude than during the S. Hemisphere summer.
   - This is the location of the Intertropical Convergence Zone (ITCZ)
• The End 😊
Insolation at Earth’s Surface
(June and December)
Absorptivity of Select Atmospheric Gases

Atmospheric “window” for Infrared radiation.
How does Specific Heat affect these lab results?