Meteorology

I. Earth's Atmosphere

A. *What is the Atmosphere*?
1. A ___________ blanket of air
2. A __________________ layer
3. Weather is a result of ___________________________ between the atmosphere and Earth's surface and between Earth's surface and the atmosphere.

B. *Composition of the Atmosphere*
1. Air is a _______________ of gases
2. Varying amounts of tiny __________ and ________________particles are suspended in the atmosphere.
3. The composition is ______ constant.
4. Major Components
   a. ________________ (N_2): ≈78%
   b. ________________(O_2): ≈21%
   c. _________________________(CO_2): ≈ 0.04%
      (1) Meteorologically important despite its presence in minute amounts.
      (2) Proportion is relatively uniform, but the percentage has been steadily rising for more than a century.

5. Variable Components
   a. _____________________________
      (1) Varies from almost zero to about four percent by volume
      (2) Significance:
         (a) It's good heat _______________.
         (b) It's a source of ___________________________ for many storms.
            i) When water changes from one phase to another it ___________ or ___________ heat.
            ii) This "hidden" heat is termed __________ heat.

   b. ______________________
      (1) Suspended _____________ and __________ particles
         (a) Most are microscopic
         (b) Visible dust can be suspended for short periods of time.
      (2) Important in cloud formation as the surfaces on which water vapor may condense.
      (3) Can be a type of pollutant and can reduce the amount of sunlight reaching Earth's surface.
      (4) Contribute to varied hues of red and orange sunrise and sunset.
      (5) Originate from____________ and __________________ sources.
         (a) Sulfur dioxide and dust from volcanic eruptions
         (b) Smoke and soot from fires and industry
         (c) Fine soil particles
         (d) Sea Salts from breaking waves
         (e) Pollen and other microorganisms

c. ___________________:

(1) Triatomic form of Oxygen (______)
(2) Forms as a result of the collision of an atom of oxygen (O), a molecule of oxygen (O_2). Reaction is a result of ______________________________ solar radiation splitting molecules of oxygen.
(3) Concentrated in the upper ______________________________.
(4) Also a photochemical pollutant at Earth's surface.

C. *Height and Structure of the Atmosphere*

1. Data Collection
   a. Balloons and Radioscondes
   b. Airplanes
   c. Rockets
   d. Satellites

2. The Vertical Extent of the Atmosphere

   a. There is _____________________________ defining the end of the atmosphere and the beginning of space.
   b. A majority of the atmosphere is _____________________Earth's surface and the gases gradually merge with the void of space.
   c. ___________________ of the atmosphere is below an altitude of 5.6 km (3.5 mi)
   d. 90 percent lies below 16 km (10 mi.)
   e. Above 100 km (62 mi.): 3.0 x 10^{-5} of gases remain. This is the official altitude of ___________.

3. Classification of the Atmosphere

   a. By *Composition*
      (1) _____________________________: Up to an altitude of about 80 km (50 mi) makeup of the air is uniform in terms of the proportions of its component gases.

      (2) _____________________________:
         (a) Above 80 km composition is not uniform
         (b) Four roughly spherical shells (lowest is nitrogen, then atomic oxygen, followed by a layers of helium, and hydrogen).

   b. By Temperature _____(Refer to the *Earth Science Reference Tables*)_____

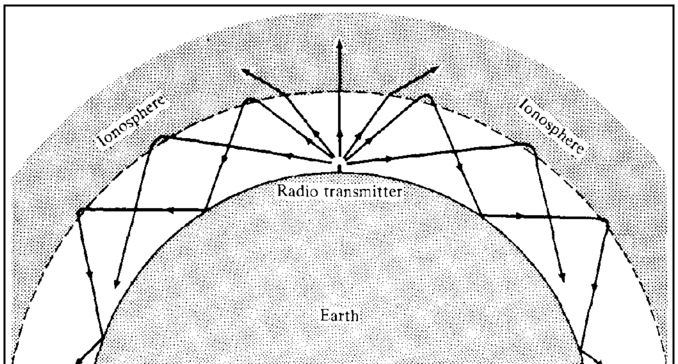
      (1) ___________________________:
         (a) The bottom layer in which we live
         (b) Temperatures _____________________with altitude ("environmental lapse rate") on the average of 6.5° C per kilometer (3.5° F per mile).
         (c) Temperature decrease continues to about 12 km but is thickest at the equator (16 km or about 10 miles) and thinnest at the poles (9 km or about 5.5 miles)
         (d) This is the chief focus of meteorologists because it is in this layer that all important weather phenomenon occur.
      (2) ___________________________:

(a) Above the troposphere.
(b) _________________________ is the boundary between the troposphere and stratosphere.
(c) Temperature remains constant to about 20 km (12 mi) and then sharply increases.
(d) Cause of temperature increase in upper stratosphere is the concentration of atmospheric ____________________.

(3) ______________________:
(a) Temperatures ____________________ with height.
(b) The coldest temperatures anywhere in the atmosphere are at the __________________.
(c) One of the least explored regions of the atmosphere.
i) Balloons can't go that high.
ii) Not accessible to lowest orbiting satellites.

(4) ______________________:
(a) No well-defined upper limit.
(b) Contains only a minute fraction of the atmosphere's total mass (rarefied and considered a vacuum.
(c) Temperatures increase due to absorption of very shortwave, high-energy solar radiation by atomic oxygen and nitrogen.
(d) While temperatures may be extremely high, the total amount of heat is very low because the gases are so sparse. As a result, an object (such as a satellite) exposed to t he air in this layer would not feel hot.

c. The ______________________:
(1) Electrically Charged layer
(2) Shortwave solar radiation ionizes molecules of nitrogen and oxygen
(3) Between 80 to 400 km altitude (50 to 250 mi) is zone of the greatest density
(4) Shortwave solar radiation ionizes molecules of nitrogen and oxygen.
(5) Actually three layers (D, E, and F)
(6) Little impact on daily weather.
(7) Used for shortwave radio communications
(8) Aurora borealis and aurora australis.



Reflection of radio waves of ionosphere. Near-vertical rays pass through the ionosphere, but those that strike at a critical angle (depending on frequency) are reflected. The earth's surface, which is also a conductor, reflects some of the rays skyward.

II. Temperature

A. *Statistical Analysis*
1. _______________________ **Temperature**: Average of the highest and lowest temperature for a day.

2. **Daily Temperature __________**: Difference between the highest and lowest temperatures for a day.

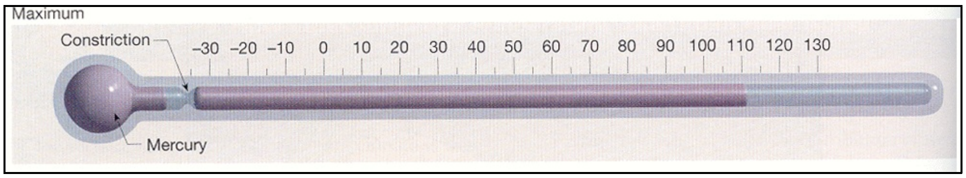
3. **Monthly _____________ Temperature**: Average of each of the daily average temperatures for a month.

4. **Annual ____________________Temperature**: Average of the each of the average monthly temperatures for a year.

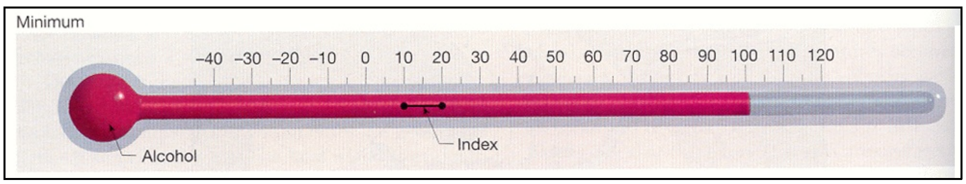
5. **Annual Temperature ____________**: Difference between the highest and lowest average monthly temps for a year.

B. *Measuring Temperature* Thermometer diagrams from: *The Atmosphere, 7th Ed.* (Lutgens, and Tarbuck, 1998)

1. ________________________________
   a. Different substances react to temperature changes differently.
   b. Liquid-in glass thermometer
   c. *Maximum and Minimum* thermometers



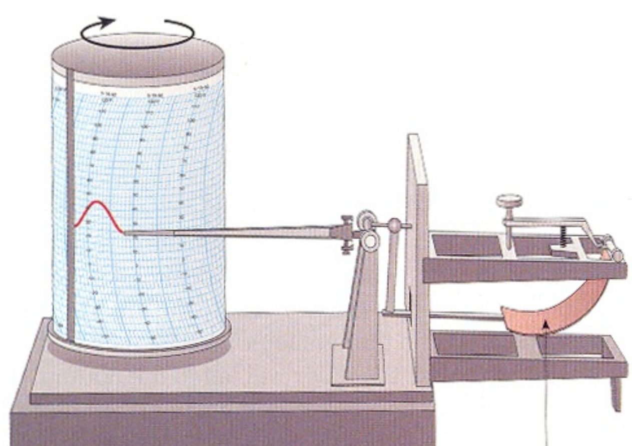
Maximum Thermometer: As temperature rises, mercury expands and is forced through the constriction which prevents a return of mercury into the bulb when temperature falls



Minimum Thermometer: A small dumbbell-shaped index in a low density liquid (alcohol) is pulled toward the bulb as the temperature drops and the column shortens. The index remains at the lowest temperature reached as liquid drains past it when temperature rises. It must be mounted horizontally.

2. _____________ strip:
   a. Two metals expand and contract uequally when heated or cooled.
   b. Causes the strips to curl.
   c. The change corresponds to the change in temperature.

3. ______________________
   a. A __________________thermometer
   b. Changes in the curvature of the bimetal strip move a pen arm.
   c. Pen marks temperatures on a calibrated chart that is attached to a clock-driven, rotating drum.



4. _________________ Thermometers

a. Thermisters (thermal resister):
   (1) Resistance to current is temperature dependent.
   (2) Higher temp = higher resistance, resulting in a reduction in flow of current
b. Measures flow of electricity which is calibrated in degrees of temperature.
c. Commonly used in *thermostats* and *radiosonde*s.

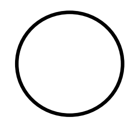
5. <u>Location of Thermometers</u>
   a. Inaccurate readings could result from placement (e.g. near a heat radiating surface or in the Sun)
   b. Ideal placement is in an ________________________________.

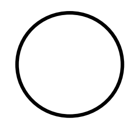
C. <u>*Map Representation of Temperature*</u>

1. <u>_______________ Models</u>
   a. Weather information at a particular point is transmitted and plotted on a surface map at that station's location. The arrangement of the data around the station location is called a station model and is standardized by international agreement

Practice Examples

   b. Plotting Temperature on a Station Model
      (1) Temperature is plotted in the upper ________ of the circle.
      (2) Always plotted in degrees _____________________.
      (3) Units (°F) are __________.





2. Isotherms
   a. ____________ connecting points of equal temperature.
   b. The larger the range in temperatures, the larger the interval used on the map.

D. <u>*Factors that cause temperature to vary from place to place*</u>.

1. <u>Land and Water</u>

   a. Differential_________________________: A mass of soil heats and cools ______________ than an equal mass of water.

   b. Land is opaque and water is more _________________
      (1) Heat is absorbed by land only at the ________________, within the top few **centimeters**.
      (2) Solar radiation penetrates to greater depths in water, to depths of several **meters**.

   c. Water is highly mobile.
      (1) _______________ currents can distribute heat throughout a ______________mass.
      (2) Heat remains near the ______________of land. No mixing can occur.

d. Specific Heat
   (1) The specific heat of liquid water is more than three times____________ than for land.
   (2) Water requires__________ heat to raise its temperature the same amount as an equal quantity of land.

2. Geographic Location
   a. Coastal locations vs Inland locations
      (1) Coastal regions have their yearly temperatures__________________ by the nearby presence of a body of water.
      (2) Coastal regions will have ___________ yearly temperature ranges than inland regions
         (a) _____________ summer temperatures
         (b) _____________ winter temperatures.

   b. Windward Coast vs. Leeward Coast
      (1) Windward: Prevailing winds from the ocean will result in a __________ annual temperature range
      (2) Leeward: ___________temperature range because winds do not carry the ocean's influence on shore.
   c. Latitude
      (1) On the average, as latitude increases average annual temperature _____________.
      (2) Higher latitudes also have a greater annual temperature __________.

   d. Northern Hemisphere vs. Southern Hemisphere

      (1) The Southern Hemisphere has a_____________ percentage of water than the Northern Hemisphere (81% covered - 20 percent more than the N. Hemisphere).
      (2) __________ temperature variations in the Southern Hemisphere.

3. Altitude
   a. As altitude increases, average annual temperature _____________.
   b. Increased altitude results in a __________daily temperature range because the greater intensity of insolation due to the less dense air

4. Ocean Currents
   a. Currents moving towards lower latitudes are ___________.

   b. Currents moving away from the equator are ____________.

   c. Caused by frictional drag on the surface by _____________.

   d. Affect coastal areas

5. Cloud Cover
   a. During the day, clouds __________ insolation back to space.

   b. At night, minimum temperature will not fall as low. Clouds ______________ terrestrial radiation and emit a portion of it toward the surface.

   c. Clouds ______________ the daily temperature range

III. **Air Pressure** ___(Also referred to as *atmospheric* or *barometric* pressure)

➢Diagrams from: *The Atmosphere, 7th Ed.* (Lutgens, and Tarbuck, 1998)

A. *The Cause of Air Pressure*

1. Air has ________________: A column of air measured to the "top" of the atmosphere with a cross-sectional area of 1 inch^2 has a weight of 14.7 pounds.

2. Pressure is defined as ______________________________________ exerted on any plane surface.
   a. Air pressure results from the_____________ of the air pressing down from above (as a result of gravity).

   b. Since air molecules move in all directions, air pressure is directed ______________________ ______________________________.

B. *Instruments for Measuring Air Pressure*

1. _____________________ Barometer

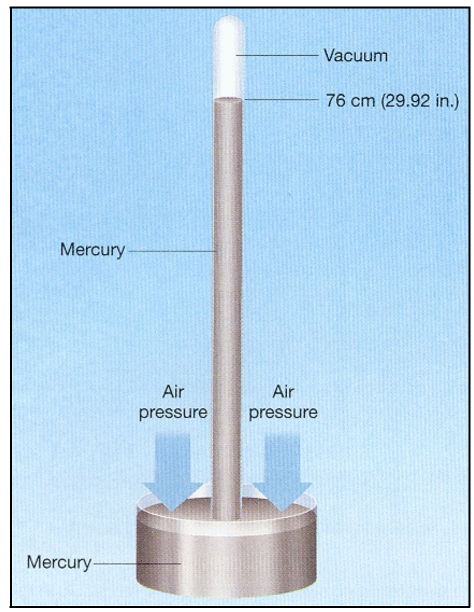
   a. Invented in 1643 by Torricelli, a student of Galileo.

   b. A tube, closed at one end and open at the other, is filled with Mercury and then inverted and immersed in an open dish of mercury.

   c. Mercury flows into the dish until the column is about 30 inches high, leaving a vacuum at the top.

   d. Higher pressure forces the mercury higher into the tube and lower pressure results in the mercury flowing out.

   e. If water was used, a tube 33 meters high would be needed.

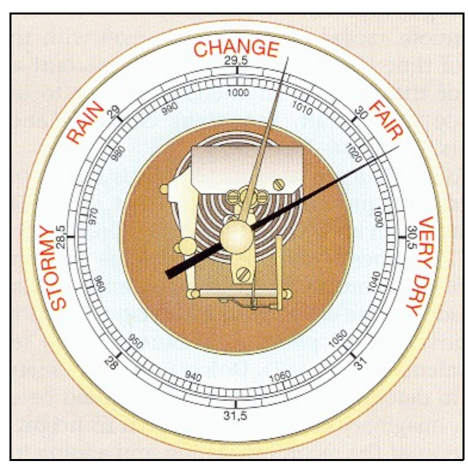


Mercury Barometer

2. ______________________ Barometer

   a. Working on the principal of a *spring balance*, a partially evacuated thin metal chamber compresses with an increase in pressure and expands with a pressure decrease.

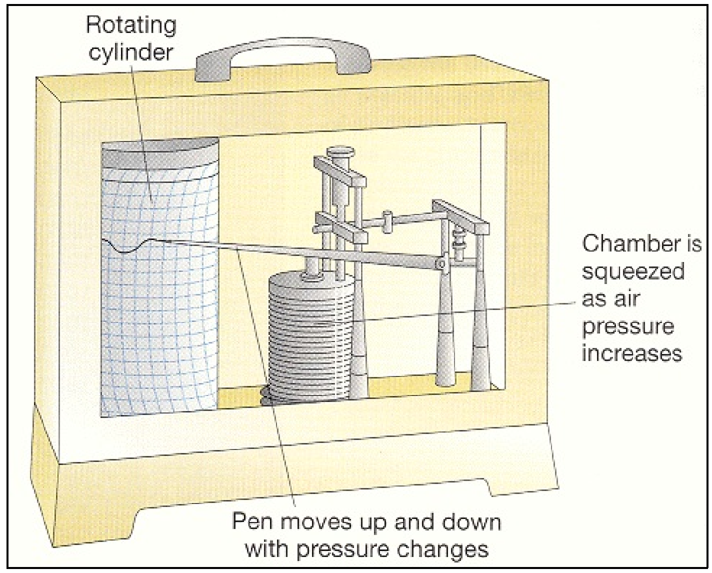
   b. It is prevented from collapsing by a spring which expands or contracts depending on the width of the chamber. An arm, magnified by levers detects these changes.



Aneroid Barometer

3. ___________________________

    a. A ___________________ aneroid barometer.
    b. A pen is attached to the arm which records pressure over time.



Barograph (Recording Barometer)

4. ____________________:
   A aneroid barometer that is calibrated to display ________________rather than pressure.

C. *Air Pressure Units*

1. _________________________(Hg):

    a. The height of the column of mercury in a liquid barometer (calibrated on an aneroid barometer).
    b. Not a ________________________________, but is an indicator of high or low pressure.
    c. Standard pressure at sea level is 29.92 inches of Hg (measured to the hundredth of an inch).

2. ___________________

    a. _______________ unit of pressure
    b. The unit of pressure used on all U.S. weather maps (since January 1940)
    c. Millibars comes from to the original term for pressure "bar". Bar is from the Greek "báros" meaning weight. A millibar is 1/1000th of a bar and is the amount of force it takes to move an object weighing a gram, one centimeter, in one second. Millibar values used in meteorology range from about 100 to 1050. At sea level, standard air pressure in millibars is 1013.2. Weather maps showing the pressure at the surface are drawn using millibars
    d. Standard pressure at seal level is 1013.2 mb (measured to the nearest tenth of a millibar for the station model).

D. *Factors Affecting Air Pressure*

1. Temperature:

   If all other factors are equal, cold __________ air exerts __________ pressure than __________ dense warmer air.

2. Humidity:
    a. The more water vapor air contains, the______________ the air is.

    b. Water vapor molecules have_______ mass than the oxygen and nitrogen molecules they displace.

    c. As a result, humid air will have __________ air pressure than drier air.

3. Altitude

   a. As altitude (elevation) increases, the density of the air _____________.

   b. The lower density of the air results in a ___________ in air pressure at high elevations.

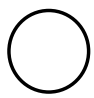
   c. _____________________*Correction*

      (1) In interpreting air pressure for the purpose of weather forecasting, meteorologists are concerned with the horizontal changes across an area.

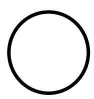
      (2) The effect of elevation must be factored out. The corrected reading for all stations determines what their pressure would be at sea level and is related to only weather conditions.

E. <u>*Air Pressure on Weather Maps*</u>

1. The station model uses an encoded format of the air pressure in *millibars.*
   a. The initial 9 or 10 and the decimal point are omitted.
   b. The number is not labeled.
   c. The encoded pressure is recorded at the ______________________ of the station model.
   d. Examples:
      (1) 1013.9 mb



      (2) 999.0 mb



2. ________________:
   a. Isolines connecting points of __________air pressure are constructed.

   b. A __________interval is used.

   c. Starts with 1000.00 mb (000 on the station model)

IV. Wind

A. <u>*What is Wind*</u>?

1. Wind is the ____.

2. Wind is the result of horizontal differences in_______________________, always flowing from regions of ___________________pressure to regions of ______________pressure.

3. ______________ heating of Earth's surface continually generates these pressure differences.

4. ________________________ is the ultimate energy source for most wind.

B. *Measuring and Recording Wind Data*

1. Instruments to Measure Wind:

   a. Wind (weather) Vanes: Indicates wind ____________.

   b. Anemometer:
      (1) Wind _________
      (2) “Anemo” comes from the Greek word “anemos” for “wind”.

   c. Aerovane: Combines a wind vane and an anemometer into one instrument.

2. Recording Wind on Maps

   a. Wind Direction
      (1) Wind is named for the direction ____________*which* it is blowing.
      (2) A northerly wind means the wind is blowing ___________________.
      (3) An arrow is drawn into the station model in the direction the wind is blowing but without the head of the arrow.

   b. Wind Speed:
      (1) ___________________, each representing 10 knots (12 mph) are drawn on the left side of the arrow as its “tail.” (One knot is equal to 1.15 mph.)
         (a) An arrow with no feather is equal to 1 to 2 knots.
         (b) Half a feather is equal to 5 knots
         (c) ____________ : A triangle represents 50 knots.

      (2) _____________:
         (a) No arrow is drawn
         (b) A circle is drawn around the station model.

C. *Factors Affecting Wind*

1. Pressure Gradient Force (Refer to Review Book Figure 7-14, page 321)

   a. The change in pressure over a ________________.

   b. Interpreted by _________________ of *isobars* on a weather map.

   c. The basic cause is ______________heating of Earth’s land-sea surface.

   d. The higher the gradient, the __________________the difference in pressure and the _______ the wind velocity.

   e. Pressure gradient has ________________as well as magnitude (at right angles to the isobars)

2. Coriolis Effect

   a. Earth's______________causes a deflection of winds so that they do not cross isobars at right angles.

   b. Deflection is to the _______________ in the Northern Hemisphere and to the ___________ in the Southern Hemisphere.

   c. It's not a true force, but is an *effect* of Earth's rotation.
      (1) Affects only the _______________ of the wind
      (2) The stronger the wind, the _____________ the deflection.
      (3) Strongest at the ___________ and nonexistent at the ________________

3. Friction
   a. Significantly influences winds near ________________________.

   b. Prevents wind speeds from continually accelerating (opposes the pressure-gradient force).

D. Geostrophic Winds

1. ___________level winds (above a few kilometers) flow in a straight path, parallel to isobars.

2. Velocities are proportional to the____________________________________ force.

3. Pressure-gradient force causes a parcel of air to accelerate towards a region of low pressure and the Coriolis force deflects winds. This deflection increases with increased wind velocity.

   a. Eventually the wind turns so that it is flowing *parallel* to the isobars with the pressure-gradient force____________ by the opposing Coriolis force (called *geostrophic balance.*)

   b. As long as the forces remain balanced, the wind flows parallel to the isobars at constant speed.

E. *Curved Air Flow (Cyclones and Anticyclones)*

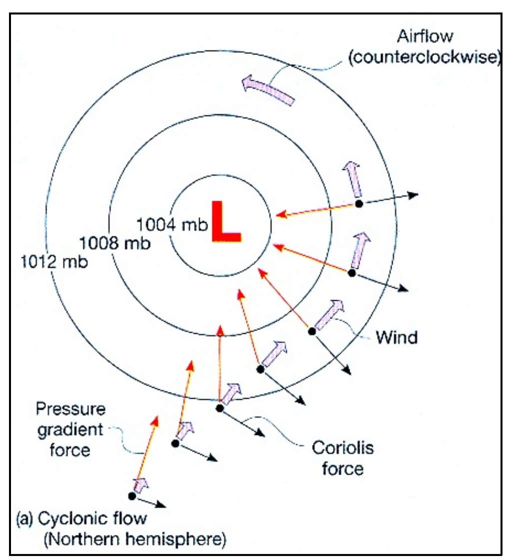
1. __________________

   a. ____________pressure

   b. Air flows ________________________and _____________________ in the Northern Hemisphere (clockwise in the S. Hemisphere)

   c. Air piles up in the low, ___________ and _________________ aloft.

   d. Rising humid air cools, forming clouds.



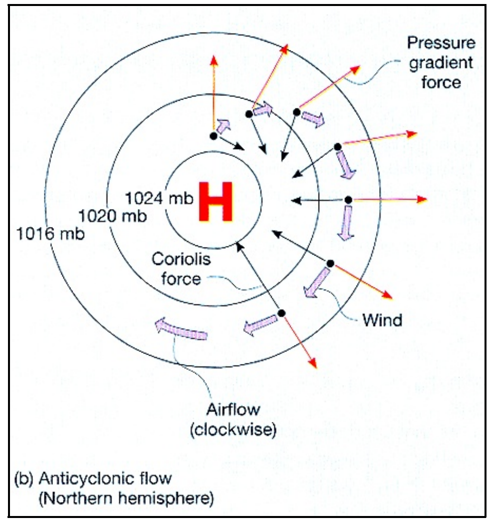
2. ____________________

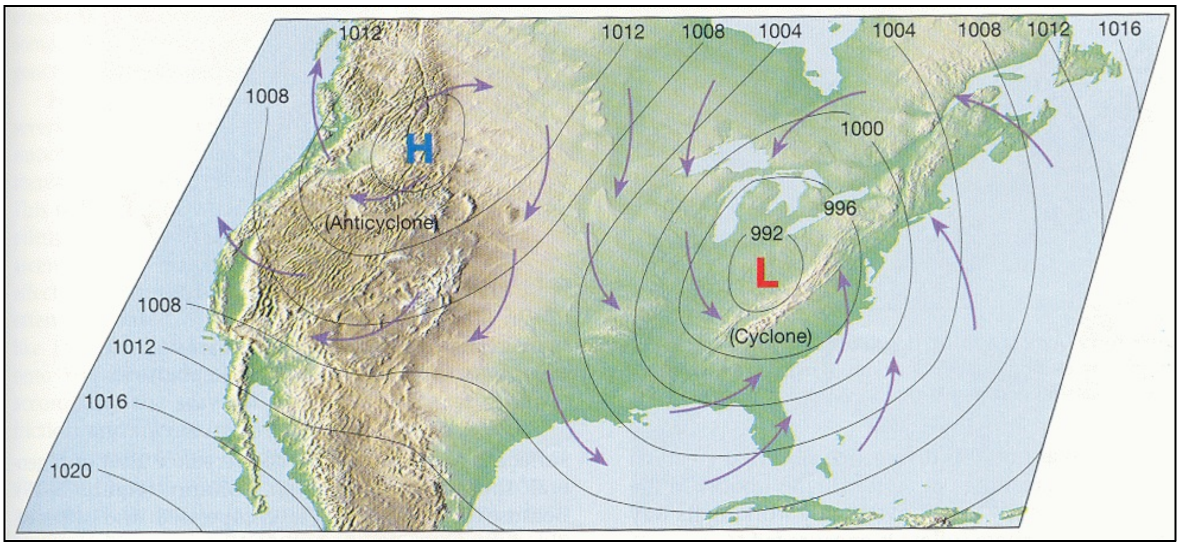
   a. _________________Pressure

   b. Air flows _______________ and ______________ (counterclockwise in the S. Hemisphere)

   c. Outflow near the surface is accompanied by __________________ aloft, and subsidence of the air column.

   d. Sinking air compresses and becomes warmer.





Cyclonic and anticyclonic winds in the Northern Hemisphere

F. *High Altitude Winds Shown on Upper Level Charts*

1. Upper-level maps show the____________ and _____________ of the upper-air winds.

2. Maps are plotted for a selected ____________ using it's pressure level (e.g., 500 mb level)

3. Contours are drawn for the actual altitude in meters at which the 500 mb level is reached.
   a. They will be__________ if there is a surface low.
      (1) The contours will form elongated bends towards the south of the map.
      (2) This is referred to as an upper level _____________________.
   b. High elevation contours indicate __________ pressure.
      (1) The contours will form elongated bends towards the north of the map.
      (2) This is referred to as an upper level _____________.

4. Upper-level winds will flow nearly _________________ to the contours.

G. *Surface Winds*

1. Friction:
    a. A factor only within the first few kilometers of Earth's surface.
    b. Friction with Earth's surface ________________ velocity which ________________the Coriolis force.
    c. Pressure-gradient force is not affected by friction, dominates, and ___________ the wind direction.
    d. Air flows at an _________________ across the isobars.
2. Smooth surface (e.g. ocean): ___________________ friction and air crosses the isobars at an angle of about 10º to 20º with a speed approximately ⅔ of geostrophic flow.
3. Rough topography (e.g. mountainous): Friction is ________________ and air can cross the isobars at an angle as high as 45º with wind speeds lowered by as much as 50%.

H. *Local Winds* (Refer Review Book Figure 7-15, page 322)

1. Land and Sea Breezes: Caused by daily temperature contrast between land and water.
    a. Sea breeze during the day

    b. Land breeze at night.

2. Mountain and Valley Breezes: Daily winds in mountainous regions similar to land and sea breezes along coasts.
    a. _____________ Breeze
        (1) Heating during the day causes air rise.
        (2) Also referred to as thermals.
        (3) Often recognized by isolated cumulus clouds
    b. ______________Breeze
        (1) _______________ at night
        (2) _______________ air drains into the valley.

3. Chinook (Foehn) Winds
    a. Strong downslope winds from mountains.
    b. Caused by a significant difference in pressure on the windward side vs. the leeward side.
    c. Air rises, and cools on the windward side and then heats due to compression as it descends on the leeward side.
    d. Can cause a temperature increase of 10 to 20 degrees Celsius in a matter of minutes.
    e. Common in the Rockies (where they are called *chinooks* meaning snow-eater) and the Alps (where they are called (*foehns*).

4. *Santa Ana Wind* is a chinook-like wind that occurs when a strong high pressure system settles to the NE of southern California with low pressure to the SW. Clockwise flow forces desert air from Arizona and Nevada westward towards the Pacific. It is funneled through the canyons of the Coast Ranges, compresses and heat the region to temperatures that can exceed 100 degrees F.

5. Katabatic or Fall Winds
   a. Cold and dense air cascades over a highland area.
   b. The air does heat as it sinks but it's still colder than the air it displaces due to its very cold original temperature.
   c. Occurs on ice sheets of Greenland and Antarctica.
   d. Called a *mistral* from the French Alps to the Mediteranean Sea.
   e. Called a *bora* from the mountains of Yugoslavia to the Adriatic Sea.

I. *The General Circulation of the Atmosphere*
1. Large Scale Air Flow - Caused by:
   a. ______________________by the Sun resulting in pressure differences.
   b. Earth's ________________

2. A Nonrotating Earth (Refer to Review Book Fig. 7-18, page 324)\
   a. A simple convection system produced by unequal heating.
   b. Greatest heating in_________________ region
   c. Polar regions ___________________
   d. Convection cell model first proposed by George Hadley in 1735.

3. The Three Cell Model for the________________ Earth (See the *Earth Science Reference Tables*)
   a. Accounts for the maintenance of Earth's heat balance and conservation of angular momentum
   b. Tropical Hadley Cell (0º to 30º latitude)
      (1) Near the equator warm air rises and releases latent heat and upper flow moves poleward .
      (2) Upper flow starts to descend between 20 and 35º latitude due to (1) radiational cooling and (2) increased Coriolis effect causing deflection to nearly west to east flow. This causes convergence.
      (3) At the surface a region of higher pressure exists at about 30º latitude. These are referred to as the *horse latitudes* due to the generally weak and variable winds.
      (4) Air flows towards the equator. This equatorward flow is deflected by the Coriolis effect forming the *trade winds.*
      (5) Doldrums: At the equator there is a weak pressure gradient with light winds and humid conditions.
      (6) *Intertropical Convergence Zone* (ITCZ): Forms where the northeast and southeast trade winds converge and is characterized by clusters of showers and thunderstorms. Many tropical cyclones originate from organized thunderstorm systems forming in the ITCZ.
   c. Ferrel Cell (mid-latitude indirect cell)
      (1) Not all the air that converges at around 30º North and South latitudes (at the *subtropical high pressure zones*) moves equatorward. Some moves towards higher latitudes.
      (2) Between 30º and 60º latitude the net surface flow is poleward.
      (3) The Coriolis force causes winds to have a strong westerly component resulting in the *prevailing northwesterlies.* (Aloft, due to cold polar air and warm tropical air the poleward directed pressure-gradient force is balanced by an equatorward-directed Coriolis force with the net result being a prevailing flow from east to west.)

d. Polar Cell (Also referred to as the Polar Hadley Cell)
    (1) Polar regions (from about 60º north and south) and extending to each pole.
    (2) Polar Easterlies: Prevailing winds are from the northeast in the Arctic and the southeast in the Antarctic.
    (3) Caused by the subsidence of cold dense air at the poles.
    (4) Eventually this cold polar air collides with the warmer westerly flow from the mid-latitudes resulting in the *polar front.*

J. <u>*Monsoons*</u>

1. _______________change in Earth's global wind circulation.
2. Monsoon refers to a wind system that exhibits a pronounced seasonal______________________, not just a "rainy season." A monsoon could result in a dry season. ("Monsoon" is from the Arabic, "mawsim" for "season.)
3. Summer Monsoon
    a. Warm moist air blows____.
    b. Results in abundant precipitation.
    c. One of the world's rainiest regions is found on the slopes of the Himalayas.
        (1) Rising moist air from the Indian Ocean cools.
        (2) Cherrapunji, India once had 25 m (82.5 ft.) of rain during a four-month period during the summer monsoon.
4. Winter Monsoon
    a. Winds ____.
    b. Results in a _______________ winter.

K. <u>*Jet Streams*</u> (Refer to Review Book Fig. 17-9, page 325)

1. Narrow and meandering belts of air found near the ____________________ .
    a. Width varies from less than 100 km to over 500 km; 60 mi. to 300 miles
    b. Altitude is 7500 to 12,000 meters; 25,000 to 40,000 feet.
2. _________________winds speeds that range from 200 km/hour to 400 km/hour (120 mi/hour to 240 mi/hr)
3. Origin:
    a. Large surface temperature contrasts produce large temperature gradients aloft (and higher wind speeds).
    b. In winter it can be warm in Florida and near-freezing a short distance away in Georgia.
    c. Polar Jet: Occurs along the polar front where large temp. contrasts are found.
    d. Jet Stream migrates with the seasons (north in summer and south in winter) and is often called the *midlatitude jet stream*.
    e. Integral part of the westerlies and is associated with outbreaks of severe thunderstorms and tornadoes when it shifts northward.
    f. Important influence on weather by supplying energy for storms but also influences storm tracks.

V. Moisture in the Atmosphere

A. *The Hydrologic Cycle (or Water Cycle)*

1. A huge system powered by Energy from the Sun in which the atmosphere is the link between _______________and ___________________________.

2. A continuous exchange of water among _____________, the _______________, and the _________________.

   a. Water leaves Earth's surface by:
      (1) ____________________ from surface water.
      (2) _____________________ from plants
      (3) ______________________: The combined total of evaporation and transpiration for a region is usually used in climate data.
      (4) Water returns to Earth's surface as ______________________ (after cloud formation).

3. Water Budget (Balance)

   a. A____ depiction of the water cycle.

   b. Amount of water cycled through the atmosphere yearly is immense (380,000 cubic kilometers) even though the amount of water vapor in the air is a___________ fraction of this total water supply.

   c. Average annual precipitation over Earth is___________ to the quantity of water evaporated.

      (1) Over continents: precipitation is_____________ than evaporation
      (2) Over oceans:______________________ is greater than _____________________ (Runoff from land keeps the ocean level constant).

B. *Change in Phase (State) of Water*

1. Requires the ________________ or _____________of heat
   a. ___________: The amount of heat necessary to raise the temperature of on gram of water one degree Celsius.
   b. __________Heat:
      (1) Heat exchanged between water and its surroundings when water changes phase.
      (2) Latent refers to "hidden" heat.

2. Changes in State
   a. Melting:
      (1) ________________water changes phase to ___________________
      (2) Requires the ________________ of heat which is stored as ________________________ ________________________.
   b. Evaporation:
      (1) ________________water changes phase to ___________________
      (2) Requires the ________________ of heat which is stored as ________________________ __________________________.

c. Condensation:
  (1) ________________water changes phase to ___________________
  (2) Requires the ________________ of heat (cooling processes) which is released as ____________________________________.

d. Freezing:
  (1) ________________water changes phase to ___________________
  (2) Requires the ________________ of heat (cooling processes) which is released as ____________________________________.

e. Sublimation and Deposition:
  (1) Sublimation is a phase change in which the__________________________________ ___________________________.
  (2) Chemists use the term for:
    (a) Solid changing phase directly to gas.
    (b) Gas changing phase directly to solid.
  (3) Meteorologists use the term sublimation only for the phases change of ______________ _________________________________.
  (4) ________________________
    (a) This is the term meteorologists use for gas changing phase directly to solid.
    (b) Water vapor is deposited as ice on solid objects
      i) Formation of "cold" clouds (temperatures below freezing).
      ii) Frost

3. Heating Curve During Phase Changes (Refer to Review Book Figure 7-7, page 306.
  a. A heating curve when read from left to right.
  b. A cooling curve when read from right to left.

C. *Humidity: Water Vapor in the Air*

1. ____________: The general term to describe the amount of water vapor in the air. Meteorologists use several methods to express the water-vapor content of air.
  a. Mixing Ratio
    (1) The________ of water vapor in a unit of air compared to the remaining mass of dry air.
    (2) Expressed as:

$$\text{Mixing Ratio} = \frac{\text{mass of water vapor (grams)}}{\text{mass of dry air (kg)}}$$

    (3) Not affected by changes in ________________ or _______________.
  b. Specific Humidity
    (1) Mass of water vapor in a unit mass of air *including* water vapor.
    (2) Amount of water vapor is usually very low, only a few percent of the total mass.
    (3) Considered the equivalent of mixing ratio.

2. Vapor Pressure and Saturation
  a. Vapor Pressure:
    (1) The ________________ pressure that results from the addition of water vapor molecules.
    (2) The part of the total atmospheric pressure due to ________________________ content.

b. Saturation
   (1) Initially, many _________ molecules will leave the water surface than will __________. (Evaporation occurs at a greater rate than condensation.)

   (2) As more water molecules evaporate and enter the air:
      (a) Vapor pressure_____________ in the air ________________the liquid
      (b) This forces more water molecules to return to the__________ (condense).

   (3) The air is saturated when:
      (a) The number of molecules of water returning to the liquid ___________the number leaving.
      (b) ________________ Vapor Pressure: The partial vapor pressure exerted by the motion of the water vapor molecules when the air is saturated.

      (c) Saturation Vapor Pressure is Temperature Dependent
         i) As temperature_______________, the rate at which water molecules leave the liquid ______________________.
         ii) Vapor pressure in the air above increases until a new _____________________ is reached.
         iii) Therefore, at ______________ temperatures it takes __________ water vapor to saturate the air.

3. Relative Humidity

   a. Ratio of the air's ________________ water vapor content compared with the amount of water vapor required for _________________ at that temperature.

   b. Saturated air has a relative humidity of 100 percent.

   c. Relative humidity can change as a result of:
      (1) Temperature change of the air

      (2) Changing the amount of moisture in the air

D. Dew Point Temperature

1. The temperature to which a parcel of air must be cooled to reach____________________
2. As air cools to this temperature, condensation or deposition occurs.
3. Formation of ________________, ___________,_____________, or ____________.
4. Dew point is a good measure of the amount of water vapor in the air.
   a. It is directly related to the______________________ of water vapor in the air.
   b. It's easy to determine.
   c. It's plotted on the weather map station model.
5. The closer the dew point temperature is to the ___________________________, the higher the relative humidity.
6. Dew point temperature will not __________________ the air temperature.

E. Measuring Humidity

1. Psychrometer (See Review Book Figure 7-9, page 312.)

2. Hair Hygrometer

3. Determination of Relative Humidity and Dew Point Temperature
   a. Refer to Review Book pages 312 - 314 and page 12 in the *Earth Science Reference Tables.*
   b. Refer to the separate handout provided.

F. Adiabatic Temperature Changes and Cloud Formation

1. Adiabatic changes

   a. Temperature changes without _________________ of heat.

   b. Expansion of air:

      (1) Causes gas molecules to move _____________________________.
      (2) Air temperature ______________.
      (3) Cause by air being _______________ (as it rises) and the ________________ air pressure around the parcel of air.

   c. Compression of air:

      (1) Causes gas molecules move _______________.
      (2) Air temperature _____________.
      (3) Caused by air ________________ (as it sinks) and the ________________ air pressure around the parcel of air.

2. Dry Adiabatic Lapse Rate

   a. Applies to _______________________ air
   b. Ascending air ______________ causing ______________ at 10º C/km.

3. Wet Adiabatic Lapse Rate

   a. As saturated air rises, latent heat is _____________________ by condensation.
   b. The added heat _________________ down the rate of cooling as the air rises.
   c. The wet adiabatic lapse rate varies with the ___________________ content (varying amounts of latent heat released).

4. ______________________ Condensation Level

   a. Altitude at which rising air has cooled to its _____________________ temperature.

   b. The lifting condensation level will be the altitude of the ________________________.

5. Requirements for Cloud Formation: Clouds are visible aggregates of minute droplets of water or tiny crystals of ice

   a. _______________ air

   b. ______________________(hydroscopic) Nuclei

   c. _______________ temperatures: Most often caused by unstable air.
      ➢So, what is the difference between unstable air and stable air?

      (1) Unstable Air:
          (a) Air that has a tendency to ___________.
          (b) It will rise until it reaches an altitude where its temperature is equal to that of the surrounding air.
          (c) As it rises it will cool adiabatically.

      (2) Stable Air
          (a) Tends to_________________ in its original position or if forced to rise will tend to sink.
          (b) It's cooler (and denser) than the surrounding air

      (3) Causes of Lifting
          (a) Localized Convective Lifting
              i) _____________heating of Earth's surface causes pockets of air to become warmer than its surroundings.
              ii) The parcels rise, causing ________________.

          (b) Convergence
              i) Air in the lower troposphere flows __________________.
              ii) Lifting results as air piles up.

          (c) Orographic Lifting (Refer to Review Book Figure 7-21, page 330)
              i) Mountain barriers force air to rise on the_________________________ side.
              ii) Air becomes _________________.
              iii) Air descends on the ___________________side and heats by compression (dry adiabatic rate)
              iv) ______________________deserts result on the *leeward side.*

          (d) *Frontal Wedging*
              i) _______________________produced by collision of warm and cold air masses.
              ii) Warm air forced____________ cooler air, forming middle-latitude cyclones (*wave cyclones*).

6. <u>Classification of Clouds</u>: For a more complete classification refer to your textbook, pages 506 - 508.

   a. Classification by Cloud Form
      (1) Cirrus
          (a) High altitude clouds made primarily of ice crystals.
          (b) Are thin and white due to small amount of water vapor at high altitudes.

(2) Cumulus
   (a) Individual masses and often form on clear days.
   (b) Often develop into vertical domes or towers.
(3) Stratus
   (a) A uniform layer that frequently covers much of the sky.
   (b) Layered clouds due to horizontal air flow.

b. *Classification by Height*
   (1) High Clouds: Above 6000 meters (20,000 ft): Clouds in this "family" are thin, white, and composed primarily of ice crystals due to small amounts of water vapor and low temperatures
   (2) Middle Clouds: Altitude range of 2000 to 6000 meters (6500 to 20,000 ft)
   (3) Low Clouds: Base below 2000 m (6500 ft)
   (4) Clouds of Vertical Development
      (a) Do not fit into any of the three height families of clouds
      (b) Bases are low and tops extend to the middle or high altitude range and are associated with unstable air.

G. *Fog*:
1. A cloud with its base at or very near the_____________.
2. Physically, there is _____ difference between fog and a cloud.
3. The basic difference is the _____________ and place of ________________.
   a. Clouds form when air rises and cools _____________________.
   b. Fog forms from ___________ or the addition of enough water vapor to cause ____________.
4. Types of Fog:
   a. Radiation Fog
      (1) Results from radiational cooling.
      (2) Occurs at night.
      (3) Requires clear skies and a high relative humidity
      (4) The cold and dense air tends to flow downslope and is often thickest in mountain valleys
      (5) After sunrise it dissipates (often said to "lift" or "burn off"). Fog evaporates from the bottom up (due to heating of the ground).

   b. Advection Fog
      (1) Results from warm air being blown over a cold surface.
      (2) Common in San Francisco, Cape Disappointment, Washington, winter months in central eastern North America.

   c. Upslope Fog
      (1) Formed when humid air moves up a gradual sloping plain or a steep mountain slope.
      (2) The upward movement of the air causes it to expand and cool adiabatically. (This is the only type of fog that forms adiabatically.)

   d. Steam Fog
      (1) Air just above warm water becomes saturated as cool air moves over it.
      (2) Air has a "steaming" appearance and is shallow (it re-evaporates in unsaturated air above)
      (3) Arctic Sea Smoke is steam fog formed in winter when cold air moves off continents and ice shelves of the north into the open ocean.

H. Dew and Frost

1. _____________
   a. Temperature next the ground cools to its dew point
   b. Water condenses on surfaces
2. ______________
   a. Air temperature is ____________ freezing.
   b. Deposition occurs on surfaces.

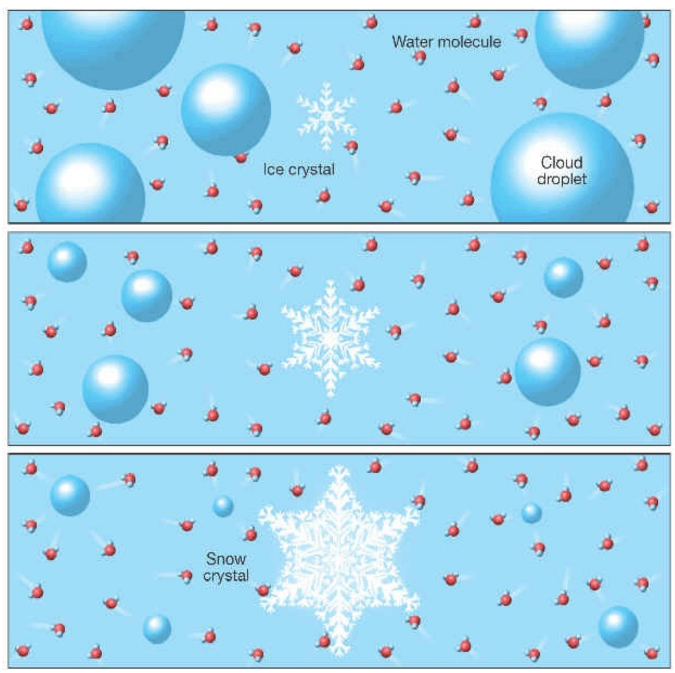
I. Precipitation: Moisture falling to Earth's_____________ from clouds.

1. Formation
   a. Collision-Coalescence in _________ Clouds (above freezing)
      (1) Larger drops __________________ with smaller ones, therefore growing in size
      (2) Drop has to survive water loss due to frictional drag (function of surface tension).
      (3) Large drops may _____________________ into small ones which in turn grow by collision and coalescence.

   b. Bergeron Process in __________Clouds (Below Freezing)
      Ice crystals grow at the expense of the supercooled water drops.

      (1) Supercooled Drops:

         (a) Pure water drops suspended in air freeze at -40º C (-40º F)
         (b) Freeze on contact with solid particles with a crystal structure resembling ice (called *freezing nuclei*)
         (c) Between 0º C and -10º C clouds consist of mainly supercooled water because freezing nuclei are sparse and don't become active until -10º C or lower.
         (d) Between -10º C and -20º C supercooled drops coexist with ice crystals.



      (2) Saturation Vapor Pressure of Supercooled Water vs. Ice Crystals
         (a) Ice crystals have a lower saturation vapor pressure above them.
         (b) Supercooled water drops loose water molecules at a greater rate than ice crystals which are solid.
         (c) When air is saturated with supercooled liquid droplets it is supersaturated with respect to ice crystals.

      (3) Ice serve as freezing nuclei (similar to condensation nuclei for condensation)
         (a) Become heavy and fall, break up (air movement) and form more crystals
         (b) Become large snowflakes that usually melt before they reach the ground resulting in rain.

2. Forms of Precipitation

a. Rain
   (1) ___________ drops with a diameter of at least 0.5 mm (usually not larger than 5 mm)
   (2) Often begins as ____________ at high altitudes

b. ___________________is composed of uniform droplets with diameters less than 0.5 mm.

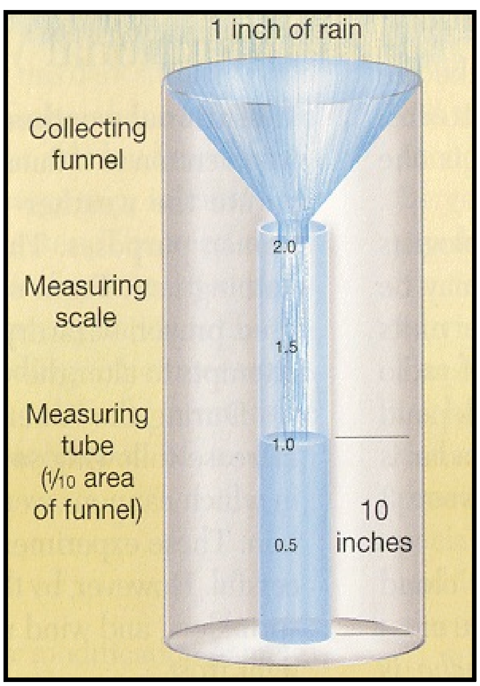
c. Snow
   (1) _______________________ that have grown as they traverse the cloud.
   (2) At temperatures greater than about -5° C, crystals usually stick together forming snowflakes.

d. ___________________
   (1) Transparent or translucent, quasi-spherical ice (diameter less than 5 mm)
   (2) Originate either as raindrops or snowflakes that have melted en route to the ground and are frozen as the move through a cold air layer near the ground.

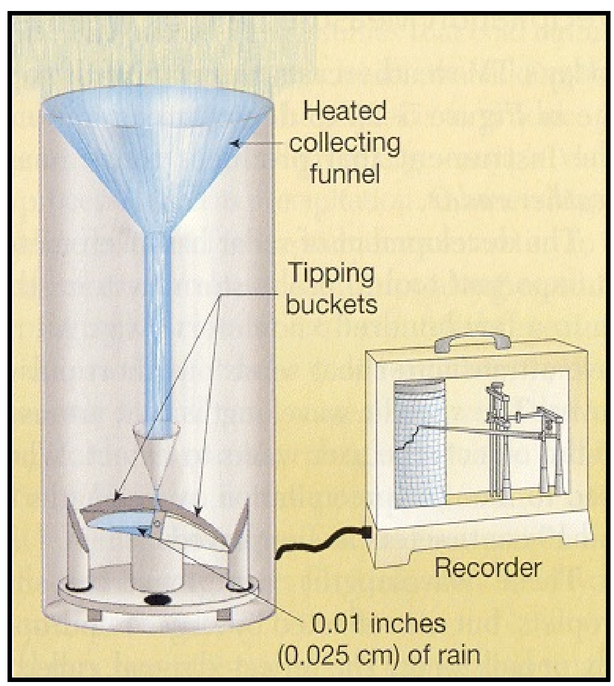
e. ___________________ (Also called *glaze*)
   (1) Rain or drizzle that freezes on impact with the ground or objects.
   (2) Subfreezing air near the ground is not thick enough for liquid drops to freeze although the liquid drops become supercooled.

f. ____________________Formed in large cumulonimbus clouds
   (1) Small balls or chunks of ice with a diameter of 5 to 75 mm (largest on record fell in Coffeyville, Kansas on Sept. 3, 1970 and was 140 mm in diameter).
   (2) Produced by successive accretion of water drops around a small kernel of ice moving through a thick cloud. Produces several layers resulting in an onion-like cross section.

3. Measuring Precipitation
   a. Rainfall



Standard Rain Gauge



Tipping-Bucket Gauge

4. Snow Records
   a. _____________ is measured
   b. ________________equivalent is determined

5. Weather Radar
   a. Specific wavelengths are reflected by larger raindrops, ice crystals, or hailstones (penetrate small cloud droplets.
   b. Echo results (reflected signal)

VI. Air Masses

A. *An Air Mass is*:

1. An _________________________of air, usually 1600 km horizontally and several kilometers vertically.
2. Characterized by ______________________________physical properties at any given ___________. (In particular, temperature and moisture content.)
3. Air Mass Weather: Generally, they ____________________ weather conditions of a region under the influence of an air mass.

B. *Source Regions* (Refer to Review Book Fig. 7-27, page 345)

1. _________________in which air masses originate and determines the ________________________ of an air mass.
2. An ideal source regions must meet two criteria.
   a. First, It must be________________ and have physically _____________________ area.
   b. Second, the area must be characterized by a general ________________of atmospheric circulation.
3. Major source regions are not found in the __________________latitudes.
   a. Middle latitudes are characterized by __________________ winds and ________________ waves (storms).
   b. Source regions are confined to ________________ and _______________ locations.

C. *Air Mass Classification*

1. Depends on:

   a. ______________________of the source region (determines temperature)
   b. The nature of the surface in the area of origin (__________________________________) which determines __________________________ conditions.

2. Naming Air Masses:
   a. Air masses are named using a two-letter code.
      (1) *First letter:*
         (a) ___________________
         (b) Designates ____________________characteristics
            i) c for continental;
            ii) m for maritime

(2) *Second letter*
   (a) ____________________
   (b) Designates ________________________conditions
   (c) P for polar; A for arctic (colder than polar); T for tropical; E for equatorial.

b. Examples
   (1) ____
   (2) ____
   (3) ____
   (4) ____

D. *Modification of Air Masses*

1. As an air mass moves it___________________ the weather of the area over which it is moving.
2. As an air mass moves it gradually becomes modified by_____________________________ which it is moving
3. Cp moves over ocean (winter): Transforms to an unstable mP air mass
   a. If colder than the surface over which it moves: lowercase *k* is added after the symbol for the air mass.
   b. If warmer than the surface over which it moves: lowercase *w* is added after the air mass symbol.

E. *Properties of North American Air Masses*

1. Continental Polar (cP) and Continental Arctic (cA)
   a. Associated with winter cold waves and the first fall freeze and last spring freeze
   b. Advance between Great Lakes and Rockies
   c. No topographic barriers between high latitudes and Gulf of Mexico
   d. Therefore cP and cA air can easily and rapidly extend far southward into the U.S.
   e. Associated with *Lake Effect Snows*
   f. Often ends heat waves in summer

2. Maritime Polar (mP)
   a. Two important sources regions influence U.S. weather
   b. North Pacific (originate as cP air in Siberia)
   c. Northwestern Atlantic from Newfoundland to Cape Cod (originally cP air masses over the continent but rarely affects U.S. weather due to westerlies)
   d. Nor'easter: Winter invasion of mP air from the Atlantic due to cyclonic winds

3. Maritime Tropical (mT)
   a. Originate over Gulf of Mexico and Caribbean Sea
   b. Often unstable (warm and moist)
   c. Winter: mT air seldom reaches the central and eastern U.S. If it does, it becomes more stable and is associated with occasional widespread precipitation (becomes mTw)
   d. Summer: Associated with hot and humid conditions with frequent cumulus development and showers or thunderstorms.

4. Continental Tropical (cT)
   a. North America has no extensive source region for cT air masses.
   b. Summer: cT air forms over northern interior Mexico and parts of the arid southwestern U.S.
   c. Unstable due to extreme temperatures but little cloud formation due to low humidity.
   d. Associated with occasional drought in the Great Plains

VII. Fronts and Wave Cyclones

A. Wave Cyclones

1. The weather primary producer in the________________________________(region between Florida and Alaska in the region of the westerlies).
2. Large _______pressure systems with counterclockwise convergent circulation. The systems generally move from ______________________.
3. Most have a cold front and often a warm front extending from the __________________________ __________________pressure.
4. The first model was constructed by Norwegian scientists during WW I.

B. Fronts

1. Fronts are ___________________ surfaces separating air masses of ___________ densities.
2. One air mass is usually ____________. Fronts can form between any two _________________ air masses.
3. ____________ the ground, the frontal surface slopes at a low angle allowing warmer air to overlie cooler air.
4. _____________________: The general term applied to warm air gliding up along a cold air mass.
5. Types of Fronts
   a. **Warm Front** (Review Book Figure 7-29, page 348)
      (1) The leading edge of an advancing ___________ air mass.
      (2) As the warm air ___________________ the cooler and receding air mass, friction with the ground slows the advance of the surface position of the front. The result is a _________________ slope of 1:200 (1 km height for every 200 km ahead of the surface location)
      (3) __________________ rate of advance and low slope produces light to moderate precipitation over a large area, ahead of the surface position of the front.
      (4) Preceded by cirrostratus clouds ("halo") and cirrocumulus ("mackerel sky')
      (5) After the front passes temperatures gradually _________________.

   b. **Cold Front** (Review Book Figure 7-30, page 349)
      (1) The leading edge of an advancing __________air mass.
      (2) Friction with the ground ________________the surface position of the front causing it to steepen as it advances.
      (3) Approximately twice as steep as a warm front (1:100).

(4) Advances at a ____________ rate (approx 35 km/hr) than a warm front (approx 25 km/hr).

(5) Forceful ________________ results in cumuloform clouds with heavy precipitation (often cumulonimbus with associated thunderstorms)

(6) Often preceded by altocumulus clouds and is followed by ______________ temperatures.

c. **Stationary** Front

(1) Produced by __________________air flow on either side of the front resulting in _____ movement of the frontal boundary.

(2) Overrunning occurs resulting in gentle to moderate precipitation

(3) ______________________on either side of the front ultimately is responsible for the formation of a low pressure center and a wave cyclone.

d. **Occluded** Front (Review Book Figure 7-31, page 349)

(1) Produced when an rapidly advancing cold front _______________ and ______________ with a warm front.

(2) A ________________________forms between the advancing cold air and the air over which the warm front is sliding.

(3) Complex weather that is often a combination ___________________________________ conditions results..

(4) Cold-Type Occluded Front: Air behind the cold front is colder than the cool air it is overtaking (most common type east of the Rockies)

(5) Warm-Type Occluded Front: Air behind the cold front is warmer than the cold air it is overtaking (more common along the Pacific Coast due to milder mP air invading colder cP air)

VIII. Wave Cyclones (Refer to Review Book Figures 7-32 and 7-33, pages 350 & 351)

A. The Life Cycle of a Wave Cyclone (Cyclone formation is called *cyclogenesis*)

1. ____________Develops (Stationary)

2. _____________Develops

3. _____________________Circulation is established

4. ____________________ begins

5. ____________________front is developed

6. The cyclone ___________________

B. Interaction of Cyclones and Anticyclones
   1. Typically found adjacent to one another (surface air from a high feeds the low)
   2. For a middle-latitude wave cyclone to form:
      a. Cyclonic flow must be established
      b. Inward flow of air near the surface must be supported by outflow aloft
   3. Convergence and Divergence of Air
      a. Upper Air Ridge:
         (1) Slowing of the jet stream results in *speed convergence* (pileup of air).
         (2) Supports a surface high (anticyclone) located downstream from the ridge
         (3) Convergence aloft results in divergence at the surface.
      b. Upper Air Trough
         (1) Jet stream winds accelerate and stretch out (*speed divergence*).
         (2) Located slightly ahead of the upper-air low pressure trough axis.
         (3) Surface cyclones form below a trough in the polar jet stream a continue to develop downstream from these upper-level waves.

   4. _____________________
      a. The tendency of air to ________________ in a whirlpool-like vortex
      b. Waves in the jet stream causes_________________ of the air masses
      c. Air mass south of jet stream near the ridge develops ______________________ flow
      d. Air mass north of jet stream near the trough develops ______________________ flow.

C. Storm Tracks
   1. ___________________flow has a steering effect on cyclonic movement. Directions are influenced by 500 millibar contours
   2. Rate is normally 20 to 50 km/hr (_____________ speeds occur in the winter with higher pressure gradients).
   3. Cyclones tend to migrate toward the _____________________
   4. _______________are embedded between cyclones and travel northeastward with the cyclones.