determine the difference ($\Delta$) between the given and desired multiple or submultiple. If you are converting from a larger to a smaller multiple or submultiple, move the decimal of the quantity to the right, the indicated difference (see example 1 above). If you are converting from a smaller to a larger multiple or submultiple, move the decimal of the quantity to the left, the indicated difference (see example 2 above). In parts a - e make your conversion and also express your answer in scientific notation.

<table>
<thead>
<tr>
<th>Number</th>
<th>Scientific Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. 9 mm</td>
<td>$0.9 , \text{cm} = \ldots , \text{cm}$</td>
</tr>
<tr>
<td>b. 3,200 km</td>
<td>$3.2 \times 10^3 , \text{km} = \ldots , \text{km}$</td>
</tr>
<tr>
<td>c. 0.2 cm</td>
<td>$2.0 , \text{mm} = \ldots , \text{mm}$</td>
</tr>
<tr>
<td>d. 68 m</td>
<td>$0.068 , \text{km} = \ldots , \text{km}$</td>
</tr>
<tr>
<td>e. 8 km/hr</td>
<td>$2.2 , \text{m/sec} = \ldots , \text{m/sec}$</td>
</tr>
</tbody>
</table>

2. The photograph below shows a portion of a meter stick with the number 60 indicating 60 centimeters and the values increasing toward the right. Complete the following parts a - c based on the photograph.

![Meter Stick Image]

a. What is the 60 cm reading equivalent to in ________ mm? ________ m?

b. Based on the portion of the meter stick above, express the readings for the indicated lettered positions in the units shown.

A ________ cm ________ mm

B ________ cm ________ mm

c. On the photograph, indicate a linear interval of 3 cm using a bracket (_______) starting from the letter A marked on the meter stick.

3. When making measurements it is customary to use a unit that is similar in scale size to the object being measured. Thus, different subunits are used depending on what is measured. Complete parts a - c of this question.

a. What is the length of the line below in centimeters? ________ cm

b. Convert the length of the line in part a to the following units.

\[ 63 \, \text{mm} \quad 0.63 \, \text{m} \quad 0.00063 \, \text{km} \]

c. Which of the above units, expressing the length of the line, is most appropriate? Explain. cm - This unit of measure is closest to actual length of line.

4. The common conversion factors for relating the metric and English systems are shown in the table below. Complete parts a - f of this question by underlining the quantity that is the larger of each pair.

<table>
<thead>
<tr>
<th>TABLE OF CONVERSIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mile (5,280 feet) = 1.6 kilometers</td>
</tr>
<tr>
<td>1 pound (weight) = 453.6 grams (mass)</td>
</tr>
<tr>
<td>1 inch = 2.54 centimeters</td>
</tr>
<tr>
<td>1 kilogram (mass) = 2.2 pounds (weight)</td>
</tr>
<tr>
<td>1 meter = 39.37 inches</td>
</tr>
<tr>
<td>1 ton (weight) = 910 kilograms (mass)</td>
</tr>
<tr>
<td>1 inch (mercury) = 0.004 millibar (mb)</td>
</tr>
</tbody>
</table>

a. 1 in or 1 cm
d. 1 hr or 600 sec
b. 1 km or 1 mi
e. 1 kg or 1 lb
c. 1000 mb or 30 in
f. 28.6 in or 952 mb

5. Conversions between the metric and English system may be used to relate everyday quantities. Use the solution to the sample problem as a guide and complete parts a - e.

SAMPLE PROBLEM: 100 mi = ________ km

Set up a proportion \[ \frac{100 \, \text{mi}}{1 \, \text{mi}} = \frac{X \, \text{km}}{1.6 \, \text{km}} \]

(Note: 1 mile = 1.6 kilometers)

Cross multiply \[ X \, \text{km} (1 \, \text{mi}) = 100 \, \text{mi} (1.6 \, \text{km}) \]

Solve and simplify \[ X \, \text{km} = \frac{100 \, \text{mi} (1.6 \, \text{km})}{1 \, \text{mi}} \]

\[ X \, \text{km} = 160 \, \text{km} \] (Answer)

a. The average depth of the mid-latitude troposphere is about 8 miles. How many kilometers does this correspond to?

\[ 12.8 \, \text{km} \]
b. One of the largest hailstones ever measured weighed 1.7 pounds. How many kilograms does this represent?

\[ 0.77 \text{ kg} \]

c. The geostationary weather satellites orbit above the equator at an altitude of 35,800 km. What is this in miles?

\[ 22,375 \text{ mi} \]

d. Weather satellites routinely provide visible light and infrared images of the earth. Infrared images taken at the 10 micrometer (\(\mu\)m) wavelength are common. What is this wavelength in inches?

\[ 0.003937 \text{ in} \]

e. The National Weather Service radar frequently use the 10 cm wavelength for detecting precipitation. What is this wavelength in feet?

\[ 0.33 \text{ ft} \]

6. A fundamental unit of importance to meteorology is temperature. In calibrating a thermometer, usually two fixed reference points are set with the interval between them divided into an arbitrary number of degree units. The three most often used scales are the Fahrenheit, Celsius, and Kelvin. Generally, temperatures in research are expressed in Kelvin units. Complete parts a - d by converting to the indicated temperature using the formulas below.

\[ F = 1.8C + 32 \quad C = \frac{F - 32}{1.8} \quad K = C + 273 \]

a. \( 41^\circ F \quad = \quad 5^\circ C \quad = \quad 278^\circ K \)

b. \( 77^\circ F \quad = \quad 25^\circ C \quad = \quad 298^\circ K \)

c. \( -40^\circ F \quad = \quad -40^\circ C \quad = \quad 233^\circ K \)

d. The air temperature in the upper regions of a severe thunderstorm may reach 215K. What is this value in \(^\circ C\) and \(^\circ F\)?

\[ -58^\circ C \quad -72.4^\circ F \]

III. Graphing and Graphical Analysis

Very often scientific observations are difficult to analyze as data or numbers in a table. By presenting data in the form of a graph, it is often much easier to find relationships among the physical properties being plotted. In simplest terms a graph is a visual representation of numerical information. A common type of graph you will encounter is illustrated below. It is a grid formed by two intersecting number lines on which are plotted two quantities. The point of intersection of the two number lines is called the origin, and the lines are called coordinate axes. Every point on the plane, or grid, can be reached by a pair of numbers, one indicating the X value (horizontal) and the other the Y value (vertical). Two points, A and B, have been plotted on the graph.

**QUESTION:**

1. The temperature profile through the lower atmosphere, provided by radiosonde data, is a useful graphical representation of temperature change with height. This can provide important information on the potential stability of the atmosphere and may be useful in predicting the likelihood of severe weather. Complete the following parts a - e of this question.

a. On the following graph plot the radiosonde data points A - I.

<table>
<thead>
<tr>
<th>Point</th>
<th>Altitude (ft.)</th>
<th>Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Surface</td>
<td>90°</td>
</tr>
<tr>
<td>B</td>
<td>2000</td>
<td>75°</td>
</tr>
<tr>
<td>C</td>
<td>3500</td>
<td>52°</td>
</tr>
<tr>
<td>D</td>
<td>6000</td>
<td>40°</td>
</tr>
<tr>
<td>E</td>
<td>7000</td>
<td>45°</td>
</tr>
<tr>
<td>F</td>
<td>8000</td>
<td>54°</td>
</tr>
<tr>
<td>G</td>
<td>9000</td>
<td>60°</td>
</tr>
<tr>
<td>H</td>
<td>11000</td>
<td>36°</td>
</tr>
<tr>
<td>I</td>
<td>15000</td>
<td>5°</td>
</tr>
</tbody>
</table>

![Graph](attachment:altitude_vs_temperature_curve.png)

b. Does the temperature continuously decrease from the surface upward? (Yes, No) If not indicate the altitude over which the temperature increases or decreases with height.

Decreases \( 0-8000 \text{ ft} \) increases \( 8000-15000 \text{ ft} \)

c. For the regions where the temperature increases or decreases use a straight edge and draw your "best fit" straight line in each region and complete the graph. Note: it is likely that the lines may not pass through each of your plotted points.

**DO NOT CONNECT THE DOTS**

d. The rate of change in °F per 1000 ft. is called the environmental lapse rate. Determine the lapse rate for each region where the temper-
nature either increases (+) or decreases (−) with height. Determine this value to the nearest tenth of a degree for each region.

<table>
<thead>
<tr>
<th>Region</th>
<th>Environmental Lapse Rate (+ or −)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ft. - 6000 ft.</td>
<td>−8.3 °F/1000 ft.</td>
</tr>
<tr>
<td>6000 ft. - 9000 ft.</td>
<td>+6.7 °F/1000 ft.</td>
</tr>
<tr>
<td>9000 ft. - 15000 ft.</td>
<td>−9.2 °F/1000 ft.</td>
</tr>
</tbody>
</table>

e. Based on this data, what would you expect the environmental temperature to be at 4000 ft.? 

56.8°F

2. The chart below shows how air pressure changes with height under average conditions. Use this chart to complete this question.

a. Using this curve, complete the missing parts of the associated table below the chart.

<table>
<thead>
<tr>
<th>Height (ft.)</th>
<th>Pressure (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13,000</td>
<td>~ 625</td>
</tr>
<tr>
<td>16,000 - 19,000</td>
<td>500</td>
</tr>
<tr>
<td>30,000</td>
<td>~ 800</td>
</tr>
<tr>
<td>8000 - 9000</td>
<td>700</td>
</tr>
</tbody>
</table>

3. Using the air pressure conversion scale between inches of mercury and millibars shown below, complete the conversions listed below.

<table>
<thead>
<tr>
<th>Millibars (mb)</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>1004</td>
<td>29.65</td>
</tr>
<tr>
<td>29.0</td>
<td>982.1</td>
</tr>
<tr>
<td>1016</td>
<td>30.00</td>
</tr>
<tr>
<td>30.25</td>
<td>1024.4</td>
</tr>
</tbody>
</table>

4. Complete the following parts of this question a - c based on the surface pressure tracings that follow. The tracing of surface air pressure with time, shown below, was recorded by an instrument called a microbarograph. Several dates and times are indicated along the curve for reference. For example, at 4 p.m. on September 21st the recorded pressure was approximately 30.20 inches.

<table>
<thead>
<tr>
<th>Date</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midnight (Start of Day)</td>
<td>~ 29.68 in</td>
</tr>
<tr>
<td>6 a.m.</td>
<td>~ 30.52 in</td>
</tr>
<tr>
<td>Noon</td>
<td>~ 30.26 in</td>
</tr>
<tr>
<td>4 p.m.</td>
<td>~ 30.20 in</td>
</tr>
<tr>
<td>One Day Interval</td>
<td>~ 30.16 in</td>
</tr>
</tbody>
</table>

b. The highest pressure was ~ 30.52 in
   The lowest pressure was ~ 29.68 in
   (For the entire tracing.)

c. When was the highest pressure recorded?
   The lowest pressure recorded? (Date/time)
   Highest ~ 9/24
   Lowest ~ 9/23
   ~ 6 p.m. ~ 3 a.m.

5. Various gases in the earth’s atmosphere are known as greenhouse gases and they strongly absorb outgoing terrestrial radiation (infrared radiation). This results in a warmer global temperature than would otherwise exist. The following graphs plot the percent of energy absorbed at various wavelengths. A value of 100% means all the energy is absorbed, while a value of 0% means none is absorbed. The wavelengths are in units called micrometers (μm). Complete parts a - d of this question.

a. For the water vapor absorption graph, shade the area under the curve of the two widest wavelength regions representing about 90% absorption. In the spaces below list the wavelength value corresponding to the midpoint of each region.

__________ μm _________ μm
b. Repeat the procedure of part a using the carbon dioxide absorption graph.

μm μm

μm μm

c. Based on the comparative widths of the shaded regions, which gas, water vapor or carbon dioxide, is contributing to the greatest absorption of terrestrial radiation?

d. The "window" in the atmosphere corresponds to the extended range of wavelengths where little absorption is occurring and hence solar radiation is reaching the surface. List the approximate range of wavelengths (μm) that corresponds to this window.

μm μm

IV. Measuring Angles—Using a Protractor

When working with angles on paper, we generally use a protractor to measure the angles. A protractor consists of a half circle divided into 180 parts, or 1° intervals. Most protractors have two scales, one starting with 0° on the right and continuing to 180° on the left, and the other starting with 0° on the left and continuing to 180° on the right. The use of the two scales makes it convenient to measure angles regardless of position. To measure an angle using the protractor, place the center of the protractor at the vertex of the angle. Place the base of the protractor on one line of sight defining the angle such that one of the lines of sight passes through the 0° on the base of the scale of the protractor. Take notice of the illustration below. Now count along the scale until the second line defining the angle is reached. The reading obtained is the size of the angle defined by the two lines. Notice the line on which we lay

Larger Angle 116°

the base of the protractor determines the direction we count. The angle we read should always be increasing as we count.

This skill will be particularly useful when you need to measure quantities like the angle of inclination or angle of insolation and relate this to the expected solar heating effect.

QUESTIONS:

1. In order to better understand angle measurements complete the following parts a - f of this question using a protractor.

   a. Measure and record the smallest angle formed between lines A and B at point X.

   \[ \sim 15° \]

   b. Measure and record the smallest angle formed between lines C and D at point E.

   \[ \sim 150° \]

   c. What is the angle formed at point G between points F and H?

   \[ 180° \]

   d. Draw a line perpendicular (forming a 90° angle) to the horizontal line shown above in part c at point G.

   e. The angle of inclination for a planet is the smallest angle between the rotation axis and the perpendicular to the orbit plane. For the diagrams below measure, to the nearest degree, the angle of inclination for each hypothetical planet and list it below the appropriate diagram.

   \[ \sim 51° \]

   \[ \sim 15° \]

   f. The angle of insolation, illustrated below, is the smallest angle between the horizon and the direction to the sun. In the three diagrams at the top of page 8, extend the arrows to the ground and measure, to the nearest degree, the angle of insolation and list it below each diagram.
V. Basic Statistics

Climatology is the study of the "average" weather conditions for a particular region over a time interval of at least 30 years. The climatologist depends heavily on the branch of mathematics known as statistics. Because climate analysis is based on large sets of data values, it is important for the climatologist to be able to condense and summarize the numerous observations and even make long term predictions.

How typical was this year's hurricane season, summer/winter temperatures, total rainfall/snowfall, extent of drought, cloud cover, sea surface temperatures, etc. as compared to a "normal" year? How useful a prediction can we make about some future trend, and how much confidence can we expect to have in such a forecast? All of these questions require that we use some aspect of statistical method to help us make inferences, test hypotheses, and determine the degree of confidence we can have in our predictions.

1. In statistics several "measures" of the middle of the data values is useful. These are the mean and the median. The mean is the sum of all the data values divided by the total number of data values. The median is the middle value when the values are listed from highest to lowest. If there is an even number of values, the median is the average of the middle two values. Determine the mean and median for the rainfall data below and write it here.

   Mean 35.12  Median 35.5

   DATA
   The total annual rainfall (rounded to the nearest inch) in the U. S. wheat belt for 50 successive years.
   28 37 44 32 42 34 45 20 37 36 33 45 38
   32 24 39 33 31 32 27 37 42 22 31 29 33
   37 26 31 30 48 36 34 39 27 36 35 30 34
   36 48 41 43 40 33 37 38 40 40 34

2. The initial climatic data such as that above, is called the raw data and we are often concerned with arranging this data such that it is more readable and usable. One of the most common ways of doing this is to construct a grouped frequency distribution. The following steps are used to complete a grouped frequency distribution:
   1. Data are arranged in order from highest to lowest.
   2. Subtracting the lowest value from the highest gives the RANGE.

3. A reasonable number of class intervals that includes all the data is established (usually 5 - 15).
4. The number of data that fall within each class interval is the FREQUENCY of the interval.
5. The sum at the bottom of the frequencies column should equal the total number of data values.

   Complete parts a and b of this question.

   a. What is the range of this data?

   b. Complete the grouped frequency distribution started below.

<table>
<thead>
<tr>
<th>CLASS INTERVAL</th>
<th>f (FREQUENCY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 - 23</td>
<td>2</td>
</tr>
<tr>
<td>24 - 27</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. In climatology, the climograph has a bar graph component that displays how yearly moisture varies on a monthly basis, for a particular region. The histogram, which is similar to a bar graph, is a common method of visually displaying the data. The class intervals are plotted along the horizontal axis, while frequencies are plotted along the vertical axis. Using the grouped frequency distribution from question 2, plot a histogram. Each bar must be placed symmetrically over each class interval such that the midpoint of each interval is in the middle of the bar. Complete the histogram started below based on the data from question 2. Note for internal 20 - 23, shown as an example, the lower and upper true class limits are 19.5 - 23.5. Plot the remaining intervals the same way.

4. A frequency polygon is drawn by connecting the midpoints of the tops of each bar in the histogram. On the histogram of question 3 mark the midpoints at the top of each bar and then connect these midpoints with a heavy solid line to create a frequency polygon for this data.
1) Use the "metric scale" above and move the decimal to the right or to the left.

   a) to get to cm move 1 space to left: 9
   b) to get to m move 3 spaces to right: 3,200
   c) to get to mm move 1 space to right: 2
   d) to get to km move 3 spaces to left: .003
   e) change 8 km to m by moving 3 spaces to the right: \( \frac{8000 \text{m}}{1 \text{hr}} \)

Change 1 hr into 3600 s: \( \frac{3000 \text{m}}{3600 \text{s}} = \frac{2.2 \text{ m/s}}{3600 \text{s}} \)

2) a) 60 cm = \( \frac{600}{100} \text{m} = 600 \text{mm} \)
   b) 60 cm = \( \frac{600}{1000} \text{m} = 0.6 \text{ m} \)
   b) 56 cm = \( \frac{560}{1000} \text{m} = 560 \text{mm} \)
   c) 59.4 cm = \( \frac{59.4}{10} \text{m} = 59.4 \text{mm} \)

3) a) 5.3 cm
   b) 5.3 cm = 53 mm
      \( \frac{5.3}{1000} \text{m} = 0.0053 \text{m} \)
      \( \frac{5.3}{1000000000} \text{km} = 0.00000053 \text{km} \)

4) The best way to approach these problems is to substitute one of the units into the appropriate quantity of the other unit.

   a) change 1 in to 2.54 cm now: \( \frac{2.54 \text{cm}}{1 \text{cm}} \)
   b) change 1 mi to 1.6 km now: \( \frac{1 \text{km}}{1.6 \text{km}} \)
   c) change 30 in into mb by multiplying: \( 30 \times 33.865 = 1015.95 \text{mb} \)
      now: 1015.95 mb is greater than 1000 mb
   d) change 1 hr to 3600 s now: \( \frac{3600 \text{s}}{600 \text{s}} \)
   e) change 1 kg to 2.2 lb now: \( \frac{2.2 \text{lb}}{11 \text{lb}} \)
f) Change 28.6 in into mb by multiplying:  
28.6 in \times 33.865 = 968.5 \text{ mb}  
now: 968.5 \text{ mb} \text{ or } 952 \text{ mb}

#5a) \quad \frac{\text{8 mi}}{1 \text{ mi}} = \frac{X}{1.6 \text{ km}}, \quad X = (8)(1.6 \text{ km}) = 12.8 \text{ km}

b) \quad \frac{1.7 \text{ lb}}{2.2 \text{ lb}} = \frac{X}{1 \text{ kg}}, \quad X = \frac{1.7 \text{ kg}}{2.2} = 0.77 \text{ kg}

c) \quad \frac{35,800 \text{ km}}{1.6 \text{ km}} = \frac{X}{1 \text{ mi}}, \quad X = 35,800 \text{ mi} = 22,375 \text{ mi}

d) Change 10 km into m: \quad \frac{10 \text{ km}}{1,000,000 \text{ m/km}} = \frac{X}{1 \text{ m}}
\quad X = 0.0001 \text{ m}

now: \quad \frac{0.0001 \text{ m}}{1 \text{ m}} = \frac{X}{39.37 \text{ in}} \quad \text{ (from table)}

e) Change 10 cm into in: \quad \frac{10 \text{ cm}}{2.54 \text{ cm}} = \frac{X}{1 \text{ in}}, \quad X = 3.94 \text{ in}

now: \quad \frac{3.94 \text{ in}}{12 \text{ in}} = \frac{X}{1 \text{ ft}}, \quad X = \frac{3.94 \text{ ft}}{12} = 0.33 \text{ ft}

#6a) \quad ^\circ \text{C} = \frac{(41^\circ - 32^\circ)}{1.8} = \frac{9^\circ}{1.8} = \frac{5^\circ \text{C} + 273}{278 \text{ K}}

b) \quad ^\circ \text{C} = \frac{(77^\circ - 32^\circ)}{1.8} = \frac{45^\circ}{1.8} = \frac{23^\circ \text{C} + 273}{298 \text{ K}}

c) \quad ^\circ \text{C} = \frac{(-40^\circ - 32^\circ)}{1.8} = \frac{-72^\circ}{1.8} = \frac{-40^\circ \text{C} + 273}{233 \text{ K}}

d) \quad K = C + 273 \text{ therefore } C = K - 273 = 215 - 273 = -58^\circ \text{C}
\quad ^\circ \text{F} = \frac{1.8(-58^\circ) + 32}{-72.4^\circ \text{F}}
\( \frac{T_2 - T_1}{H_2 - H_1} = \frac{400^\circ F - 90^\circ F}{6,000' - 0'} = \frac{-50^\circ F}{6,000' + 1,000} = -8.3^\circ F \)

\( \frac{T_2 - T_1}{H_2 - H_1} = \frac{600^\circ F - 400^\circ F}{9,000' - 6,000'} = \frac{200^\circ F}{3,000' + 1,000} = 6.7^\circ F \)

\( \frac{T_2 - T_1}{H_2 - H_1} = \frac{5^\circ F - 600^\circ F}{15,000' - 9,000'} = \frac{-555^\circ F}{6,000' + 1,000} = -9.2^\circ F \)

\( e) \) Between the ground and 4,000 ft the atmosphere is cooling 8.3\(^\circ\)F per 1000 ft (calculated above). Therefore, the atmosphere will have cooled 4 times this rate because the problem is considering a 4000 ft change in altitude.

\[ T = ?? \] 
\[ = -8.3^\circ F \] 
\[ = -8.3^\circ F \] 
\[ = -8.3^\circ F \] 
\[ = -8.3^\circ F \] 
\[ T = 90^\circ F \]

Atmosphere will be \((4)(8.3^\circ F) = 33.2^\circ F\) cooler at 4000 ft. Subtract 33.2\(^\circ\)F from 90\(^\circ\)F (starting \(T\))

\[ \frac{-8.3^\circ F}{1,000' + 1,000'} = -33.2^\circ F \ (cooling) \]

\[ 90 - 33.2^\circ F = 56.8^\circ F \]

\( #3 \)

\[ 1000 \text{ in} \text{ mb} \div 33.865 = 29.65 \text{ in} \]

\[ 29.0 \text{ in} \times 33.865 = 982.1 \text{ mb} \]

\[ 1013.0 \text{ mb} \div 33.865 = 30.00 \text{ in} \]

\[ 30.25 \text{ in} \times 33.865 = 1024.4 \text{ mb} \]