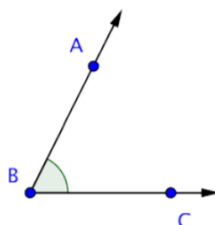


2.5: Finding Angle Measurements

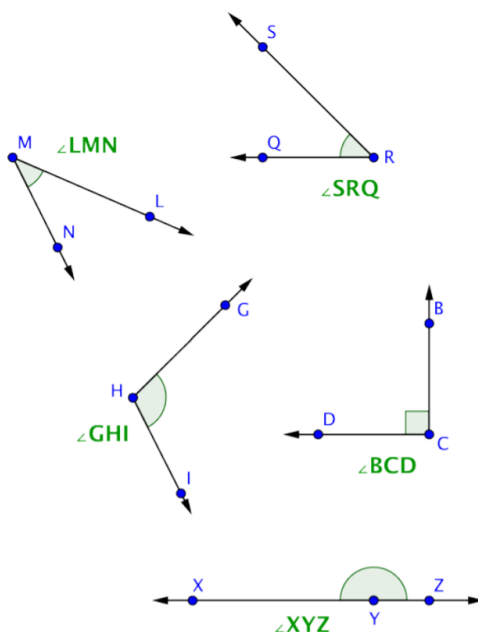
Angles

Lines, line segments, points, and rays are the building blocks of other figures. For example, two rays with a common endpoint make up an **angle**. The common endpoint of the angle is called the **vertex**.

The angle ABC is shown below. This angle can also be called $\angle ABC$, $\angle CBA$ or simply $\angle B$. When you are naming angles, be careful to include the vertex (here, point B) as the middle letter.



The image below shows a few angles on a plane. Notice that the label of each angle is written “point-vertex-point,” and the geometric notation is in the form $\angle ABC$.



Sometimes angles are very narrow; sometimes they are very wide. When people talk about the “size” of an angle, they are referring to the arc between the two rays. The length of the rays has nothing to do with the size of the angle itself. Drawings of angles will often include an arc (as shown above) to help the reader identify the correct ‘side’ of the angle.

Think about an analog clock face. The minute and hour hands are both fixed at a point in the middle of the clock. As time passes, the hands rotate around the fixed point, making larger and smaller angles as they go. The length of the hands does not impact the angle that is made by the hands.

An angle is measured in degrees, represented by the symbol $^\circ$. A circle is defined as having 360° . (In skateboarding and basketball, “doing a 360” refers to jumping and doing one complete body rotation.

A **right angle** is any degree that measures exactly 90° . This represents exactly one-quarter of the way around a circle. Rectangles contain exactly four right angles. A corner mark is often used to denote a right angle, as shown in right angle DCB below.

Angles that are between 0° and 90° (smaller than right angles) are called **acute angles**. Angles that are between 90° and 180° (larger than right angles and less than 180°) are called **obtuse angles**. And an angle that measures exactly 180° is called a **straight angle** because it forms a straight line.

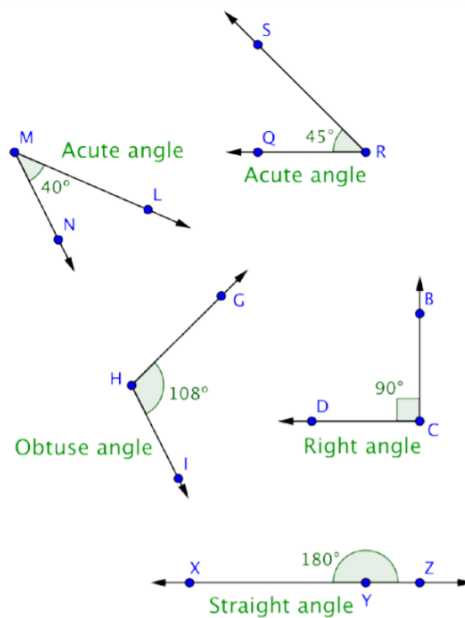
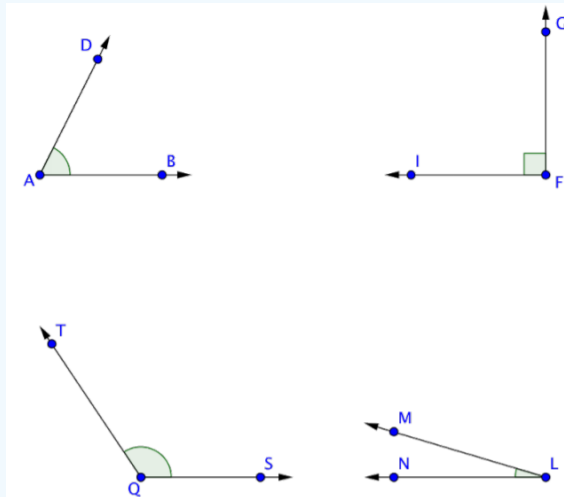


Figure 2.5.5: Examples of Angles

✓ Example 2.5.4

Label each angle below as acute, right, or obtuse.



Solution

You can start by identifying any right angles.

$\angle GFI$ is a right angle, as indicated by the corner mark at vertex F.

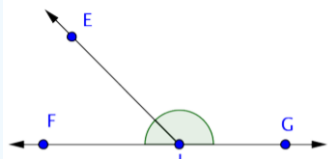
Acute angles will be smaller than $\angle GFI$ (or less than 90°). This means that $\angle DAB$ and $\angle MLN$ are acute.

$\angle TQS$ is larger than $\angle GFI$, so it is an obtuse angle.

Answer: $\angle DAB$ and $\angle MLN$ are acute angles. $\angle GFI$ is a right angle. $\angle TQS$ is an obtuse angle.

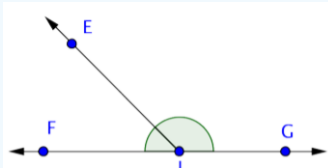
✓ Example 2.5.5

Identify each point, ray, and angle in the picture below.

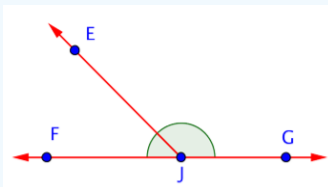


Solution

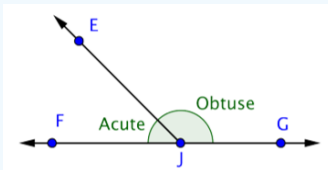
Begin by identifying each point in the figure. There are 4: E, F, G, and J.



Now find rays. A ray begins at one point, and then continues through another point towards infinity (indicated by an arrow). Three rays start at point J: \overrightarrow{JE} , \overrightarrow{JF} , and \overrightarrow{JG} . But also notice that a ray could start at point F and go through J and G, and another could start at point G and go through J and F. These rays can be represented by \overrightarrow{GF} and \overrightarrow{FG} .



Finally, look for angles. $\angle EJG$ is obtuse, $\angle EJF$ is acute, and $\angle FJG$ is straight. (Don't forget those straight angles!)



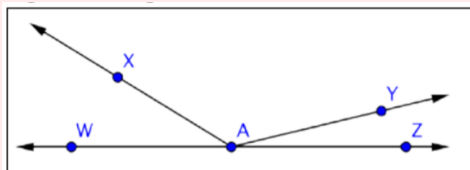
Answer: Points: E, F, G, J

Rays: \overrightarrow{JE} , \overrightarrow{JG} , \overrightarrow{JF} , \overrightarrow{GF} , \overrightarrow{FG}

Angles: $\angle EJG$, $\angle EJF$, $\angle FJG$

Try It Now 2

Identify the acute angles in the given image:



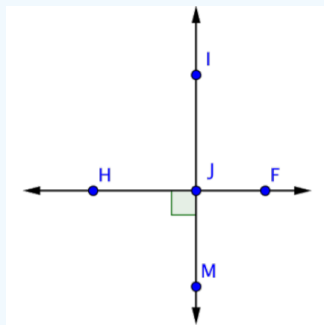
Finding Angle Measurements

Understanding how parallel and perpendicular lines relate can help you figure out the measurements of some unknown angles. To start, all you need to remember is that perpendicular lines intersect at a 90° angle and that a straight angle measures 180° .

The measure of an angle such as $\angle A$ is written as $m\angle A$. Look at the example below. How can you find the measurements of the unmarked angles?

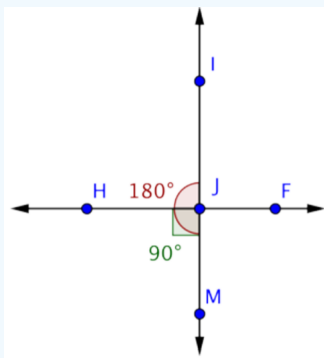
✓ Example 2.5.8

Find the measurement of $\angle IJF$.



Solution

Only one angle, $\angle HJM$, is marked in the image. Notice that it is a right angle, so it measures 90° . $\angle HJM$ is formed by the intersection of lines \overleftrightarrow{IM} and \overleftrightarrow{HF} . Since \overleftrightarrow{IM} is a line, $\angle IJM$ is a straight angle measuring 180° .

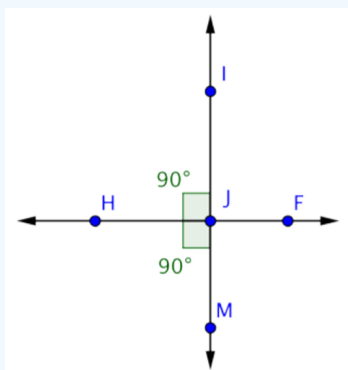


You can use this information to find the measurement of $\angle HJI$:

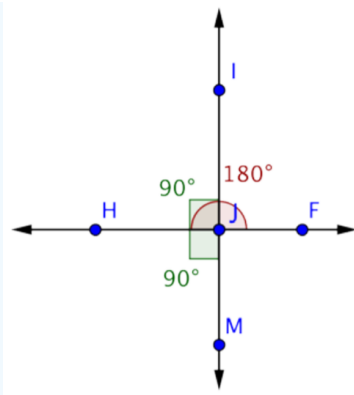
$$m\angle HJM + m\angle HJI = m\angle IJM$$

$$90^\circ + m\angle HJI = 180^\circ$$

$$m\angle HJI = 90^\circ$$



Now use the same logic to find the measurement of $\angle IJF$. $\angle IJF$ is formed by the intersection of lines \overleftrightarrow{IM} and \overleftrightarrow{HF} . Since \overleftrightarrow{HF} is a line, $\angle HJF$ will be a straight angle measuring 180° .

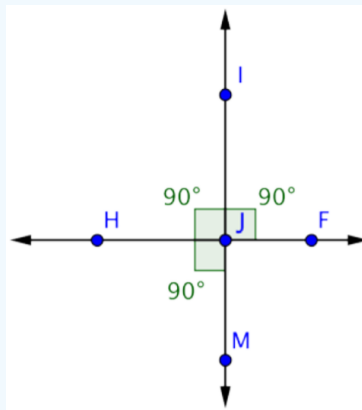


You know that $\angle HJI$ measures 90° . Use this information to find the measurement of $\angle IJF$:

$$m\angle HJM + m\angle IJF = m\angle HJF$$

$$90^\circ + m\angle IJF = 180^\circ$$

$$m\angle IJF = 90^\circ$$



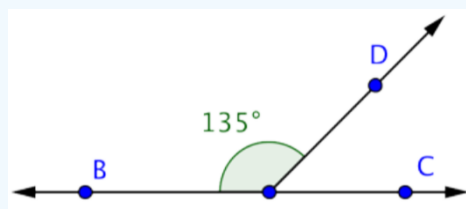
Answer: $m\angle IJF = 90^\circ$

In this example, you may have noticed that angles $\angle HJI$, $\angle IJF$, and $\angle HJM$ are all right angles. (If you were asked to find the measurement of $\angle FJM$, you would find that angle to be 90° , too.) This is what happens when two lines are perpendicular—the four angles created by the intersection are all right angles.

Not all intersections happen at right angles, though. In the example below, notice how you can use the same technique as shown above (using straight angles) to find the measurement of a missing angle.

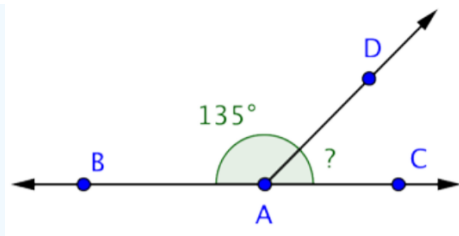
✓ Example 2.5.9

Find the measurement of $\angle DAC$.

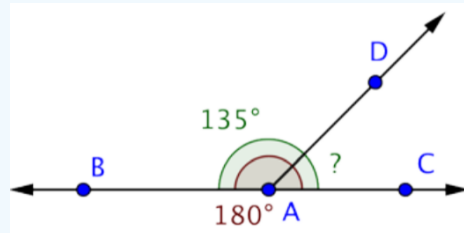


Solution

This image shows the line \overleftrightarrow{BC} and the ray \overrightarrow{AD} intersecting at point A. The measurement of $\angle BAD$ is 135° . You can use straight angles to find the measurement of $\angle DAC$.



$\angle BAC$ is a straight angle, so it measures 180° .

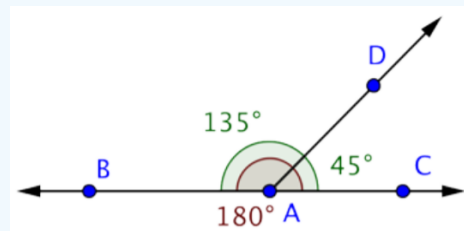


Use this information to find the measurement of $\angle DAC$.

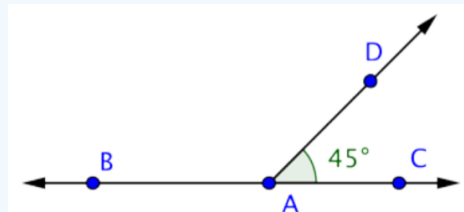
$$m\angle BAD + m\angle DAC = m\angle BAC$$

$$135^\circ + m\angle DAC = 180^\circ$$

$$m\angle DAC = 45^\circ$$

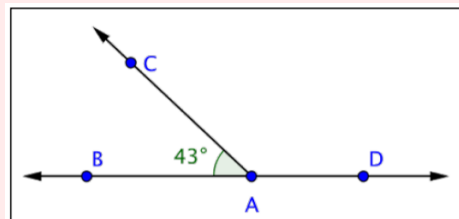


Answer: $m\angle DAC = 45^\circ$



Try It Now 2

Find the measurement of $\angle CAD$.



Supplementary and Complementary

In the example above, $m\angle BAC$ and $m\angle DAC$ add up to 180° . Two angles whose measures add up to 180° are called **supplementary angles**. There's also a term for two angles whose measurements add up to 90° , they are called **complementary**

angles.

One way to remember the difference between the two terms is that “corner” and “complementary” each begin with c (a 90° angle looks like a corner), while straight and “supplementary” each begin with s (a straight angle measures 180°).

If you can identify supplementary or complementary angles within a problem, finding missing angle measurements is often simply a matter of adding or subtracting.

✓ Example 2.5.10

Two angles are supplementary. If one of the angles measures 48°, what is the measurement of the other angle?

Solution

Two supplementary angles make up a straight angle, so the measurements of the two angles will be 180°.

$$m\angle A + m\angle B = 180^\circ$$

You know the measurement of one angle. To find the measurement of the second angle, subtract 48° from 180°.

$$48^\circ + m\angle B = 180^\circ$$

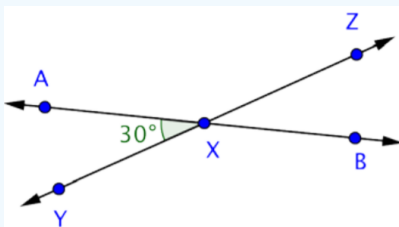
$$m\angle B = 180^\circ - 48^\circ$$

$$m\angle B = 132^\circ$$

Answer: The measurement of the other angle is 132°

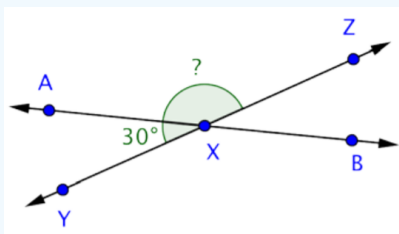
✓ Example 2.5.11

Find the measurement of $\angle AXZ$.



Solution

This image shows two intersecting lines, \overleftrightarrow{AB} and \overleftrightarrow{YZ} . They intersect at point X, forming four angles. Angles $\angle AXY$ and $\angle AXZ$ are supplementary because together they make up the straight angle $\angle YXZ$.

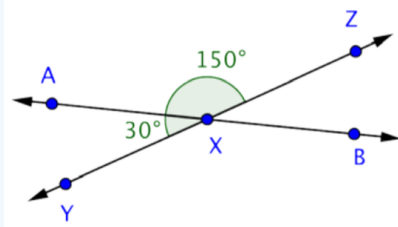


Use this information to find the measurement of $\angle AXZ$.

$$m\angle AXY + m\angle AXZ = m\angle YXZ$$

$$30^\circ + m\angle AXZ = 180^\circ$$

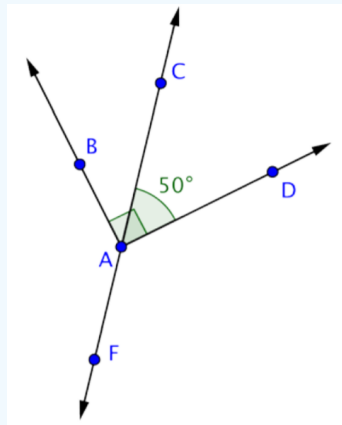
$$m\angle AXZ = 150^\circ$$



Answer: $m\angle AXZ = 150^\circ$

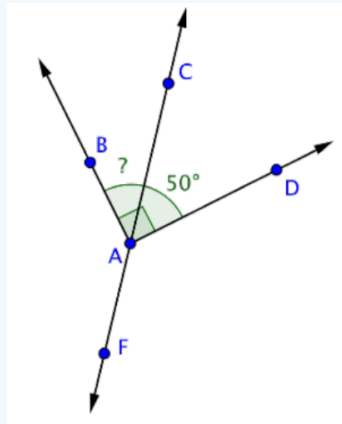
✓ Example 2.5.12

Find the measurement of $\angle BAC$.



Solution

This image shows the line \overleftrightarrow{CF} and the rays \overrightarrow{AB} and \overrightarrow{AD} , all intersecting at point A. Angle $\angle BAD$ is a right angle. Angles $\angle BAC$ and $\angle CAD$ are complementary because together they create $\angle BAD$.

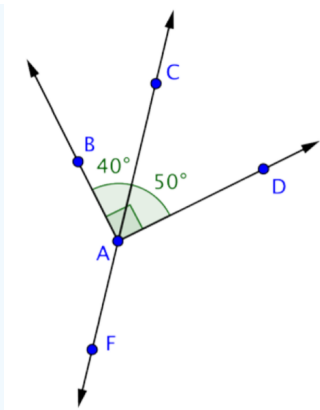


Use this information to find the measurement of $\angle BAC$.

$$m\angle BAC + m\angle CAD = m\angle BAD$$

$$m\angle BAC + 50^\circ = 90^\circ$$

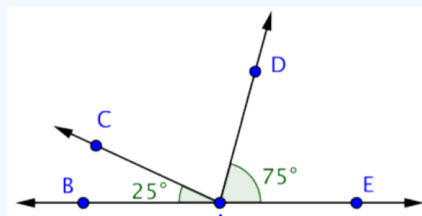
$$m\angle BAC = 40^\circ$$



Answer: $m\angle BAC = 40^\circ$

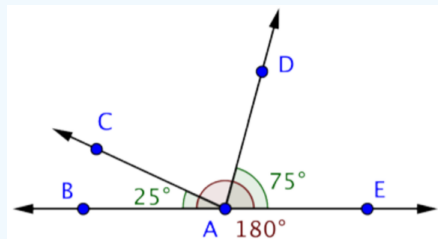
✓ Example 2.5.13

Find the measurement of $\angle CAD$.



Solution

You know the measurements of two angles here: $\angle CAB$ and $\angle DAE$. You also know that $m\angle BAE = 180^\circ$.



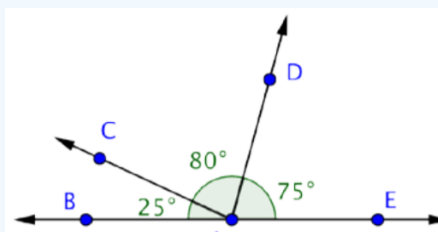
Use this information to find the measurement of $\angle CAD$.

$$m\angle BAC + m\angle CAD + m\angle DAE = m\angle BAE$$

$$25^\circ + m\angle CAD + 75^\circ = 180^\circ$$

$$m\angle CAD + 100^\circ = 180^\circ$$

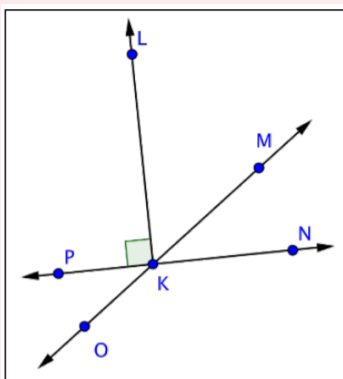
$$m\angle CAD = 80^\circ$$



Answer: $m\angle CAD = 80^\circ$

Try It Now 3

Which pair of angles is complementary?



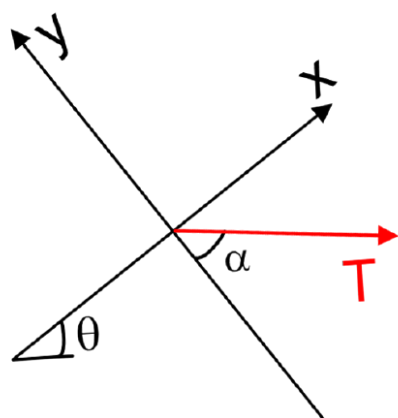
- A) $\angle PKO$ and $\angle MKN$
- B) $\angle PKO$ and $\angle PKM$
- C) $\angle LKP$ and $\angle LKN$
- D) $\angle LKM$ and $\angle MKN$

Summary

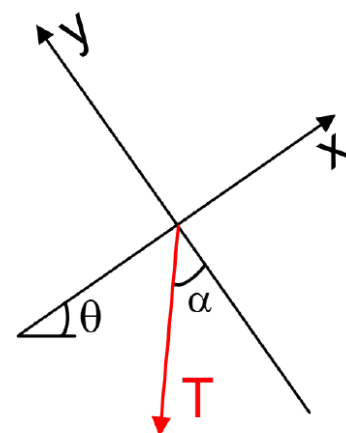
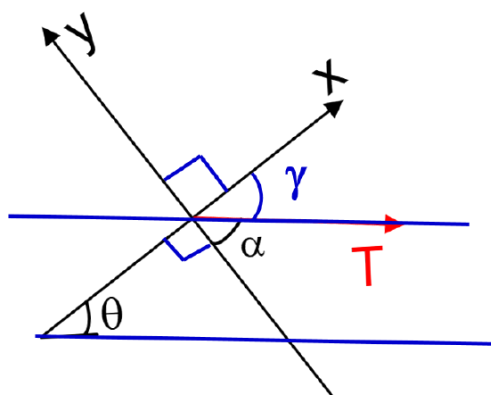
Parallel lines do not intersect, while perpendicular lines cross at a 90° angle. Two angles whose measurements add up to 180° are said to be supplementary, and two angles whose measurements add up to 90° are said to be complementary. For most pairs of intersecting lines, all you need is the measurement of one angle to find the measurements of all other angles formed by the intersection.

Try It Now Answers

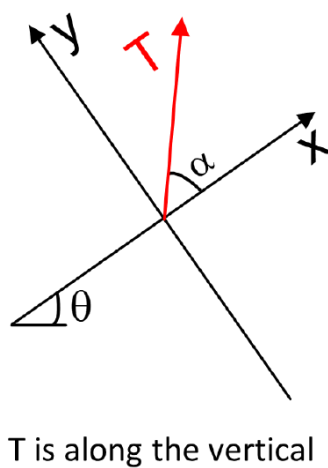
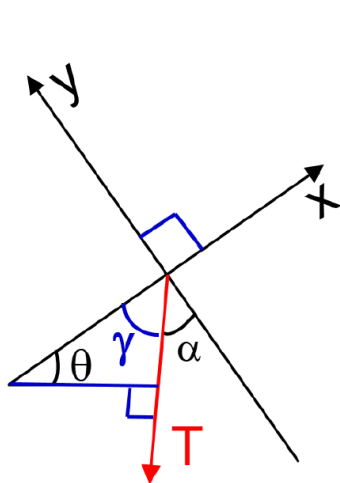
- C) $FH \parallel EG$; both EG and FH are marked with \gg on each line, and those markings mean they are parallel.
- 137° ; $\angle BAD$ is a straight angle measuring 180° . Since $\angle BAC$ measures 43° , the measure of $\angle CAD$ must be $180^\circ - 43^\circ = 137^\circ$.
- D) $\angle LKM$ and $\angle MKN$; the measurements of two complementary angles will add up to 90° . $\angle LKP$ is a right angle, so $\angle LKN$ must be a right angle as well. $\angle LKM + \angle MKN = \angle LKN$, so $\angle LKM$ and $\angle MKN$ are complementary.



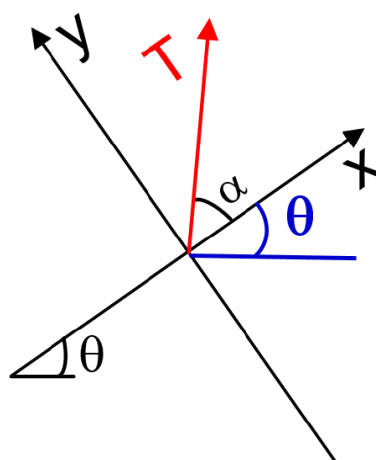
T is along the horizontal

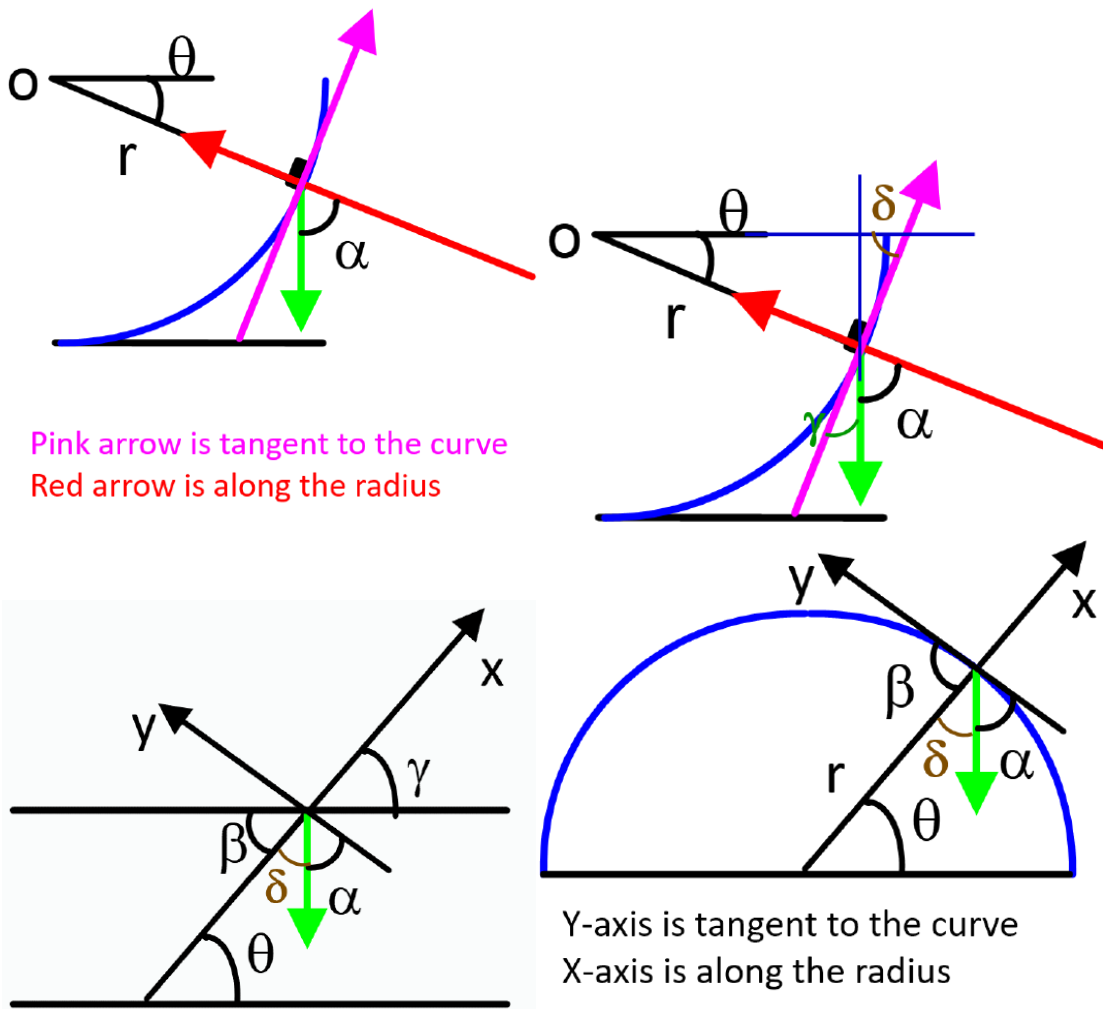


T is along the vertical



T is along the vertical





Two lines are **parallel** if they do not meet, no matter how far they are extended. The symbol for parallel is \parallel . In Figure 2.5.1, $\overleftrightarrow{AB} \parallel \overleftrightarrow{CD}$. The arrow marks are used to indicate the lines are parallel.

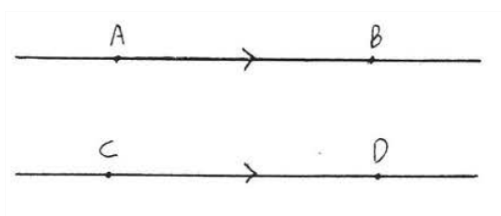


Figure 2.5.1: \overleftrightarrow{AB} and \overleftrightarrow{CD} are parallel. They do not meet no matter how far they are extended.

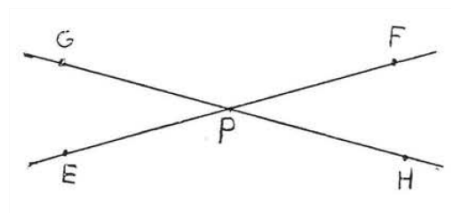


Figure 2.5.1: \overleftrightarrow{EF} and \overleftrightarrow{GH} are not parallel. They meet at point P.

We make the following assumption about parallel lines, called the **parallel postulate**.

Theorem 2.5.1: Parallel Postulate

The probabilities assigned to events by a distribution function on a sample space are given by

Through a point not on a given line one and only one line can be drawn parallel to the given line. So in Figure 2.5.3, there is exactly one line that can be drawn through C that is parallel to \overleftrightarrow{AB} .

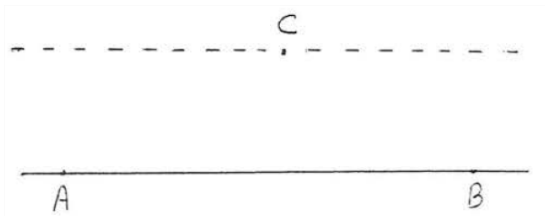


Figure 2.5.3: There is exactly one line that can be drawn through C parallel to \overleftrightarrow{AB} .

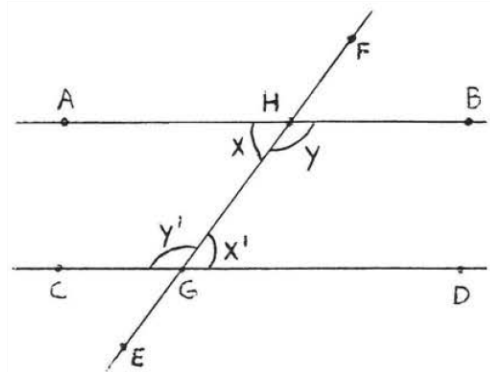


Figure 2.5.4: \overleftrightarrow{EF} is a transversal.

A **transversal** is a line that intersects two other lines at two distinct points. In Figure 2.5.4, \overleftrightarrow{EF} is a transversal. $\angle x$ and $\angle x'$ are called **alternate interior angles** of lines \overleftrightarrow{AB} and \overleftrightarrow{CD} . The word "alternate," here, means that the angles are on different sides of the transversal, one angle formed with \overleftrightarrow{AB} and the other formed with \overleftrightarrow{CD} . The word "interior" means that they are between the two lines. Notice that they form the letter "Z." (Figure 2.5.5). $\angle y$ and $\angle y'$ are also alternate interior angles. They also form a "Z" though it is stretched out and backwards. Viewed from the side, the letter "Z" may also look like an "N."

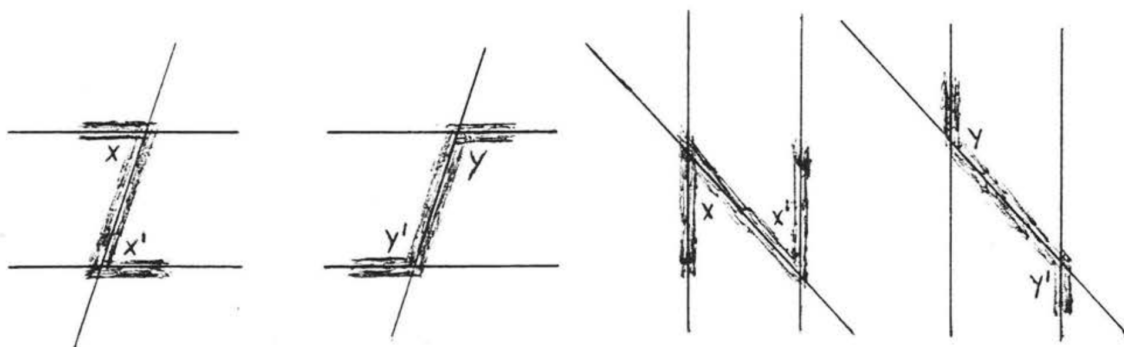


Figure 2.5.5: Alternate interior form the letters "Z" or "N". The letter may be stretched out or backwards.

Alternate interior angles are important because of the following theorem:

Theorem 2.5.1 The "Z" Theorem

If two lines are parallel then their alternate interior angles are equal, If the alternate interior angles of two lines are equal then the lines must be parallel,

In Figure 2.5.6, \overleftrightarrow{AB} must be parallel to \overleftrightarrow{CD} because the alternate interior angles are both 30° . Notice that the other pair of alternate interior angles, $\angle y$ and $\angle y'$, are also equal. They are both 150° . In Figure 2.5.7, the lines are not parallel and none of the alternate interior angles are equal.

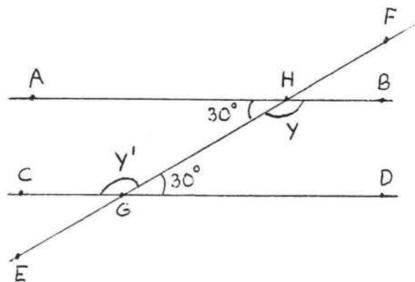


Figure 2.5.6: The lines are parallel and their alternate interior angles are equal.

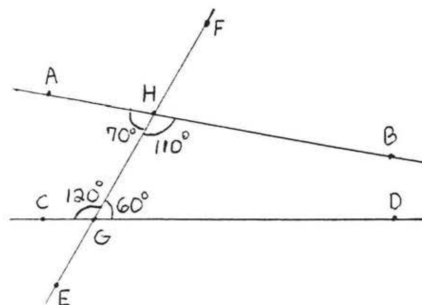
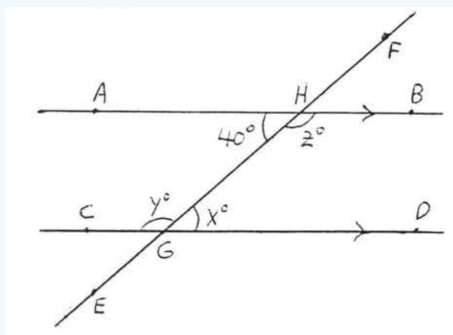


Figure 2.5.7: The lines are not parallel and their alternate interior angles are not equal.

The Proof of Theorem 2.5.1 is complicated and will be deferred to the appendix.

Example 2.5.1

Find x , y and z :



Solution

$\overleftrightarrow{AB} \parallel \overleftrightarrow{CD}$ since the arrows indicate parallel lines. $x^\circ = 40^\circ$ because alternate interior angles of parallel lines are equal.
 $y^\circ = z^\circ = 180^\circ - 40^\circ = 140^\circ$.

Answer: $x = 40$, $y = 140$, $z = 140$.

Corresponding angles of two lines are two angles which are on the same side of the two lines and the same side of the transversal, In Figure 2.5.8, $\angle w$ and $\angle w'$ are corresponding angles of lines \overleftrightarrow{AB} and \overleftrightarrow{CD} . They form the letter "F." $\angle x$ and $\angle x'$, $\angle y$ and $\angle y'$, and $\angle z$ and $\angle z'$ are other pairs of corresponding angles of \overleftrightarrow{AB} and \overleftrightarrow{CD} . They all form the letter "F", though it might be a backwards or upside down "F" (Figure 2.5.9).

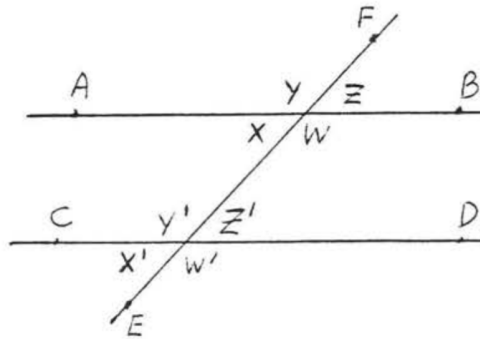


Figure 2.5.8: Four pairs of corresponding angles are illustrated.

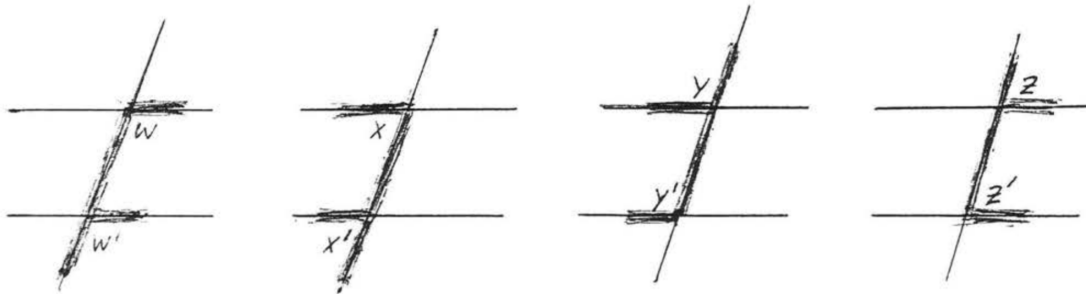


Figure 2.5.9: Corresponding angles form the letter "F," though it may be a backwards or upside down "F."

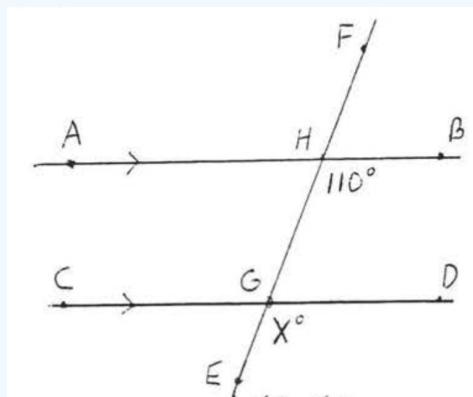
Corresponding angles are important because of the following theorem:

Theorem 2.5.2: The "F" Theorem

If two lines are parallel then their corresponding angles are equal. If the corresponding angles of two lines are equal then the lines must be parallel.

✓ Example 2.5.2

Find x :



Solution

The arrow indicate $\overleftrightarrow{AB} \parallel \overleftrightarrow{CD}$. Therefore $x^\circ = 110^\circ$ because x° and 110° are the measures of corresponding angles of the parallel lines \overleftrightarrow{AB} and \overleftrightarrow{CD} .

Answer: $x = 110$.

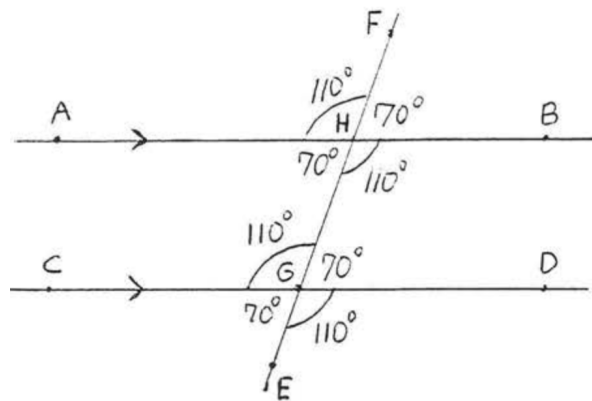


Figure PageIndex10: Each pair of corresponding angles is equal.

Notice that we can now find all the other angles in Example PageIndex2. Each one is either supplementary to one of the 110° angles or forms equal vertical angles with one of them (Figure PageIndex10). Therefore **all** the corresponding angles are equal. Also each pair of alternate interior angles is equal. It is not hard to see that if just one pair of corresponding angles or one pair of alternate interior angles are equal then so are all other pairs of corresponding and alternate interior angles.

Proof of Theorem 2.5.2: The corresponding angles will be equal if the alternate interior angles are equal and vice versa. Therefore Theorem 2.5.2 follows directly from Theorem 2.5.1.

In Figure 2.5.11, $\angle x$ and $\angle x'$ are called **interior angles on the same side of the transversal**. (In some textbooks, interior angles on the same side of the transversal are called cointerior angles.) $\angle y$ and $\angle y'$ are also interior angles on the same side of the transversal. Notice that each pair of angles forms the letter "C." Compare Figure 2.5.11 with Figure 10 and also with Example 2.5.1. The following theorem is then apparent:

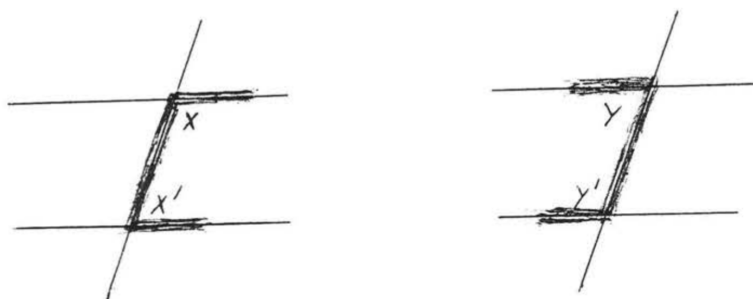


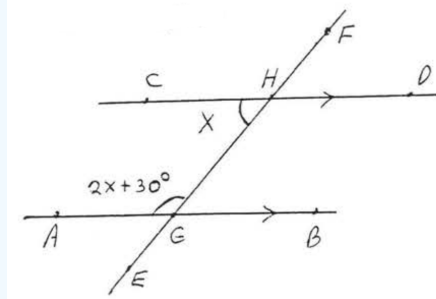
Figure 2.5.11: Interior angles on the same side of the transversal form the letter "C". It may also be a backwards "C."

Theorem 2.5.3: The "C" Theorem

If two lines are parallel then the interior angles on the same side of the transversal are supplementary (they add up to 180°). If the interior angles of two lines on the same side of the transversal are supplementary then the lines must be parallel.

Example 2.5.3

Find x and the marked angles:



Solution

The lines are parallel so by Theorem 2.5.3 the two labelled angles must be supplementary.

$$\begin{aligned}
 x + 2x + 30 &= 180 \\
 3x + 30 &= 180 \\
 3x &= 180 - 30 \\
 3x &= 150 \\
 x &= 50
 \end{aligned}
 \tag{2.5.1}$$

$$\angle CHG = x = 50^\circ$$

$$\angle AGH = 2x + 30 = 2(50) + 30 = 100 + 30 = 130^\circ.$$

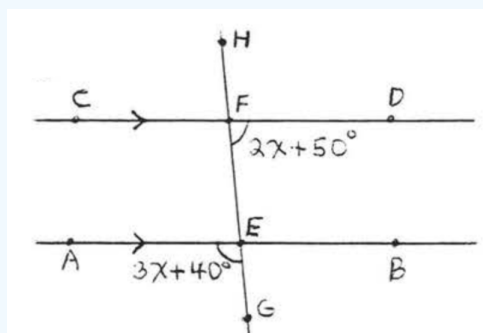
Check:

$$\begin{array}{rcl}
 x + 2x + 3x & = & 180^\circ \\
 50 + 2(50) + 30 & | & \\
 50 + 130 & | & \\
 180 & | &
 \end{array}$$

Answer: $x = 50$, $\angle CHG = 50^\circ$, $\angle AGH = 130^\circ$.

✓ Example 2.5.4

Find x and the marked angles:



Solution

$\angle BEF = 3x + 40^\circ$ because vertical angles are equal. $\angle BEF$ and $\angle DFE$ are interior angles on the same side of the transversal, and therefore are supplementary because the lines are parallel.

$$\begin{aligned}
 3x + 40 + 2x + 50 &= 180 \\
 5x + 90 &= 180 \\
 5x &= 180 - 90 \\
 5x &= 90 \\
 x &= 18
 \end{aligned}
 \tag{2.5.2}$$

$$\angle AEC = 3x + 40 = 3(18) + 40 = 54 + 40 = 94^\circ$$

$$\angle DFE = 2x + 50 = 2(18) + 50 = 36 + 50 = 86^\circ$$

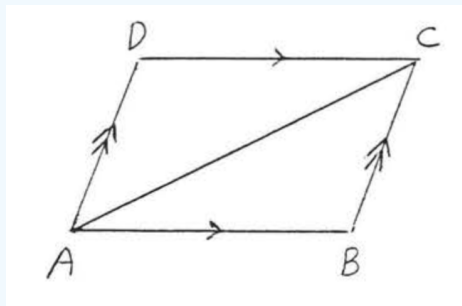
Check:

$$\begin{array}{r}
 3x + 40 + 2x + 50 = 180 \\
 3(18) + 40 + 2(18) + 50 \\
 54 + 40 + 36 + 50 \\
 94 + 86 \\
 180
 \end{array}$$

Answer: $x = 18$, $\angle AEG = 94^\circ$, $\angle DFE = 86^\circ$.

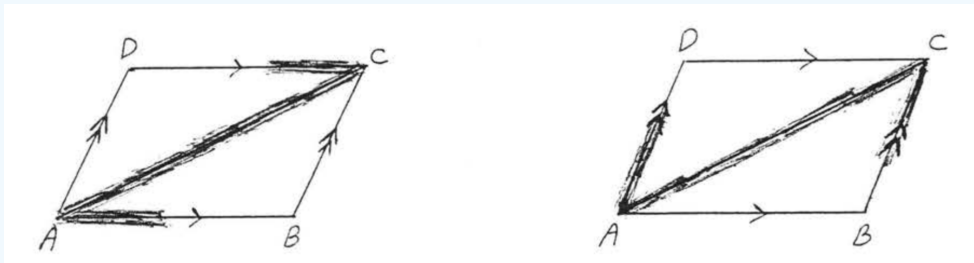
✓ Example 2.5.5

List all pairs of alternate interior angles in the diagram, (The single arrow indicates \overleftrightarrow{AB} is parallel to \overleftrightarrow{CD} and the double arrow indicates \overleftrightarrow{AD} is parallel to \overleftrightarrow{BC}).



Solution

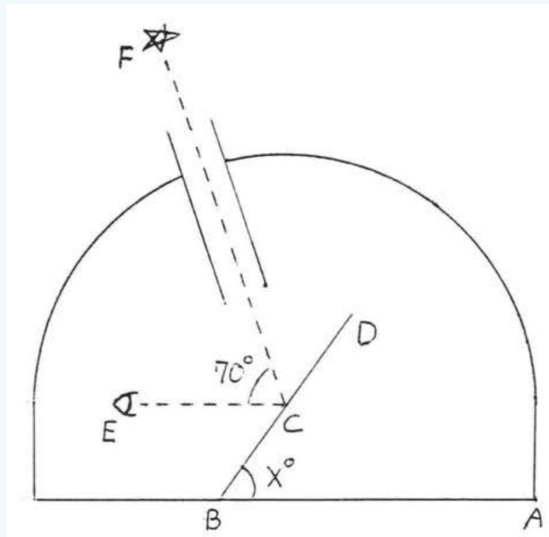
We see if a letter Z or N can be formed using the line segments in the diagram (Figure 2.5.12),



Answer: $\angle DCA$ and $\angle CAB$ are alternate interior angles of lines \overleftrightarrow{AB} and \overleftrightarrow{CD} . $\angle DAC$ and $\angle ACB$ are alternate interior angles of lines \overleftrightarrow{AD} and \overleftrightarrow{BC} .

✓ Example 2.5.6

A telescope is pointed at a star 70° above the horizon, What angle x° must the mirror BD make with the horizontal so that the star can be seen in the eyepiece E ?



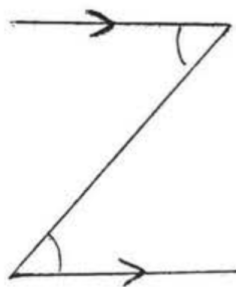
Solution

$x^\circ = \angle BCE$ because they are alternate interior angles of parallel lines \overleftrightarrow{AB} and \overleftrightarrow{CE} . $\angle DCF = \angle BCE = x^\circ$ because the angle of incidence is equal to the angle of reflection. Therefore

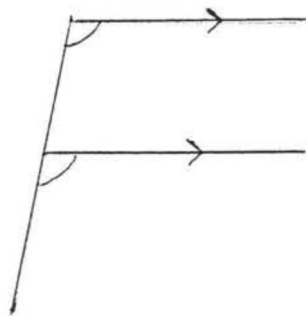
$$\begin{aligned} x + 70 + x &= 180 \\ 2x + 70 &= 180 \\ 2x &= 110 \\ x &= 55 \end{aligned} \tag{2.5.3}$$

Answer: 55°

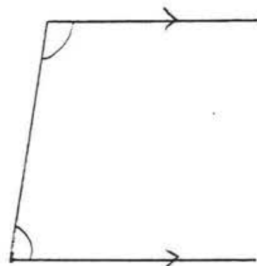
SUMMARY



Alternate interior angles of parallel lines are equal. They form the letter "Z."



Corresponding angles of parallel lines are equal. They form the letter "F."



Interior angles on the same sides of the transversal of parallel lines are supplementary. They form the letter "G."

Historical Note

The parallel postulate given earlier in this section is the equivalent of the fifth postulate of Euclid's Elements. Euclid was correct in assuming it as a postulate rather than trying to prove it as a theorem. However this did not become clear to the mathematical world until the nineteenth century, 2200 years later. In the interim, scores of prominent mathematicians attempted unsuccessfully to give a satisfactory proof of the parallel postulate. They felt that it was not as self-evident as a postulate should be, and that it required some formal justification.

In 1826, N. I. Lobachevsky, a Russian mathematician, presented a system of geometry based on the assumption that through a given point more than one straight line can be drawn parallel to a given line (Figure 2.5.13). In 1854, the German mathematician Georg Bernhard Riemann proposed a system of geometry in which there are no parallel lines at all. A geometry in which the parallel postulate has been replaced by some other postulate is called a non-Euclidean geometry. The existence of these geometries shows that the parallel postulate need not necessarily be true. Indeed Einstein used the geometry of Riemann as the basis for his theory of relativity.

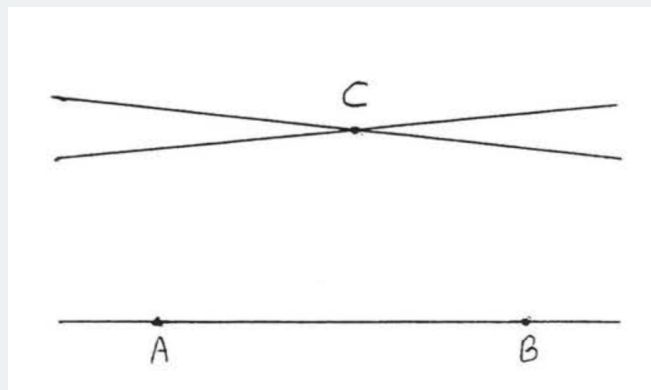


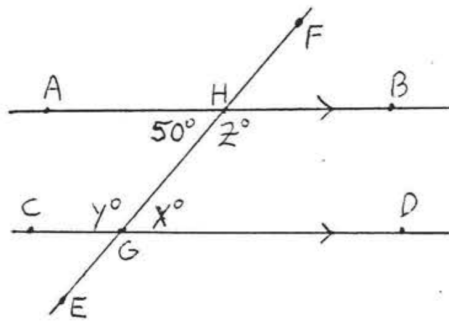
Figure PageIndex13: In the geometry of Lobachevsky, more than one line can be drawn through C parallel to AB .

Of course our original parallel postulate makes the most sense for ordinary applications, and we use it throughout this book. However, for applications where great distances are involved, such as in astronomy, it may well be that a non-Euclidean geometry gives a better approximation of physical reality.

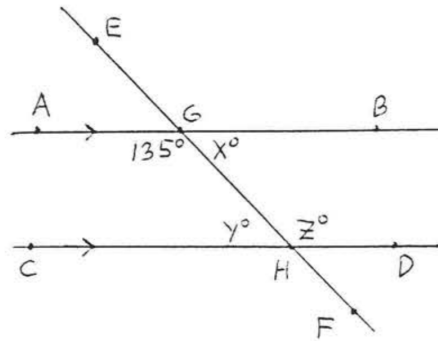
Problems

For each of the following, state the theorem(s) used in obtaining your answer (for example, "alternate interior angles of parallel lines are equal"). Lines marked with the same arrow are assumed to be parallel,

1 - 2. Find x , y , and z :

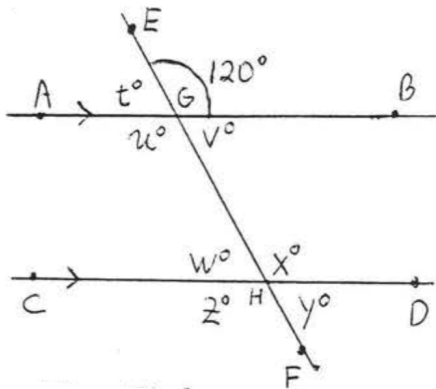


1.

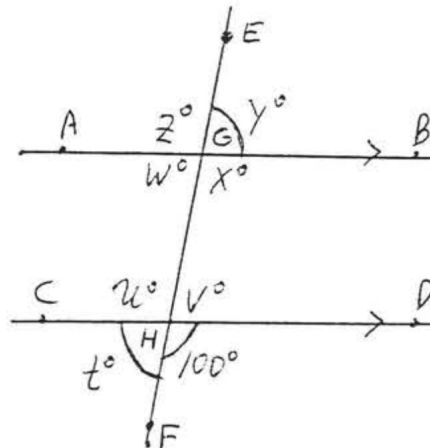


2.

3 - 4. Find t , u , v , w , x , y , and z :

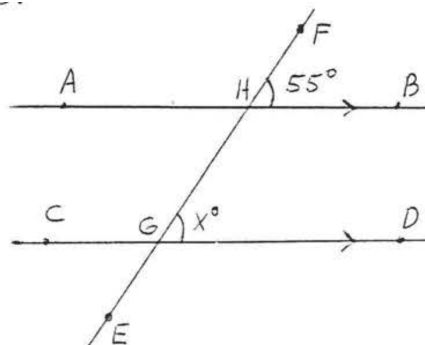


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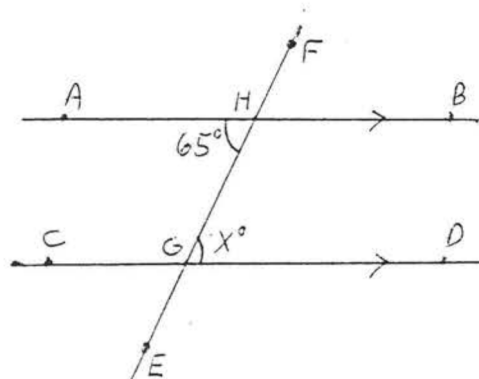


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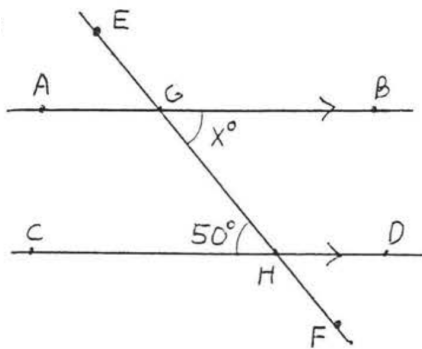
5 - 10. Find x :



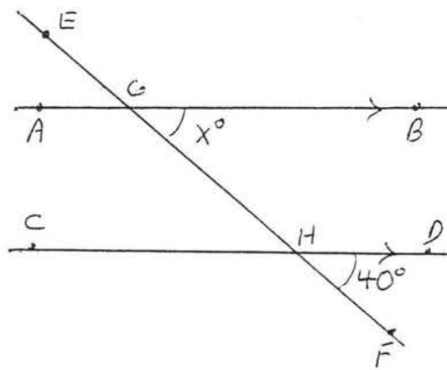
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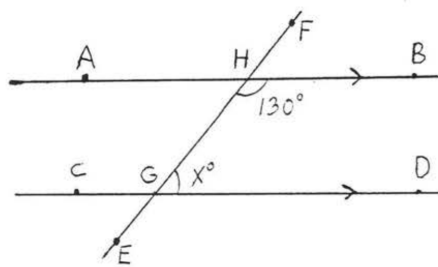
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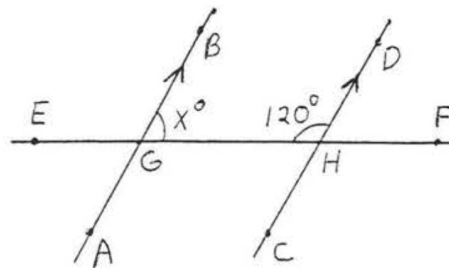
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8.

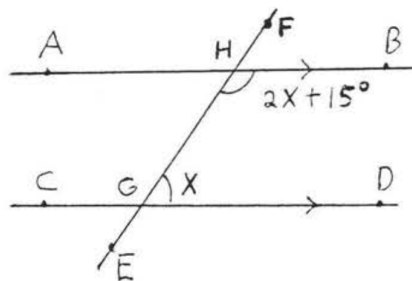


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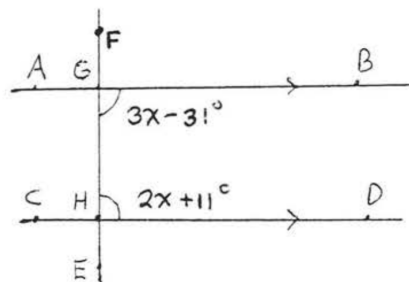


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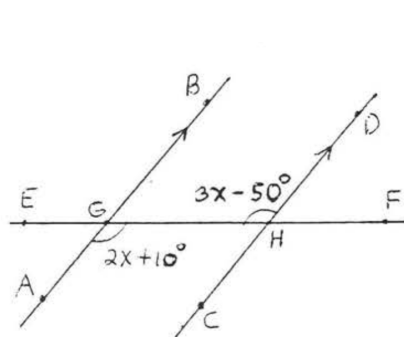
11 - 18. Find x and the marked angles:



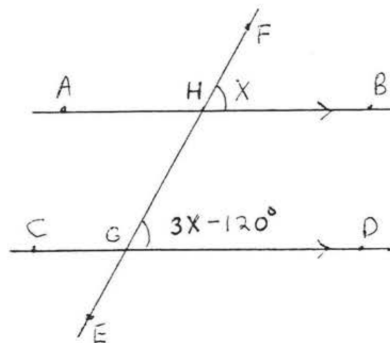
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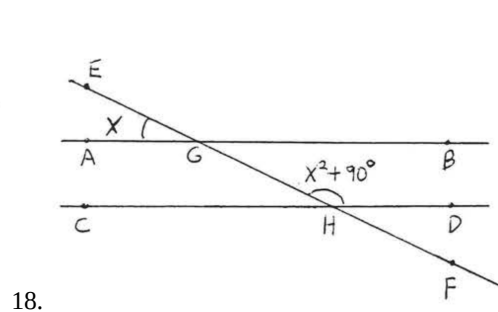
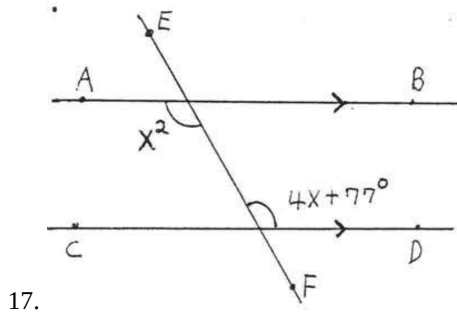
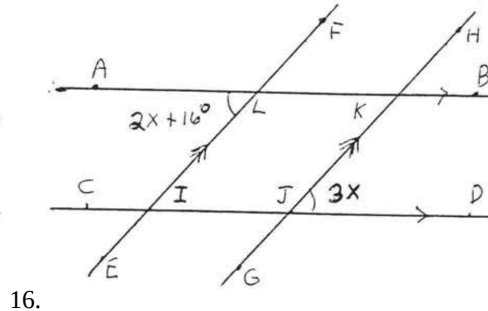
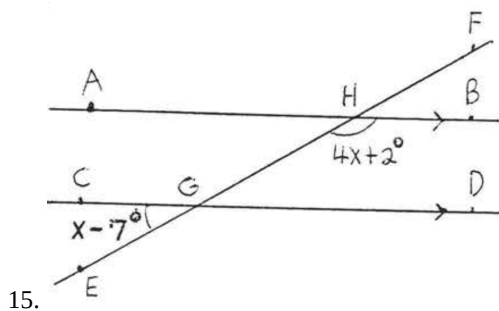
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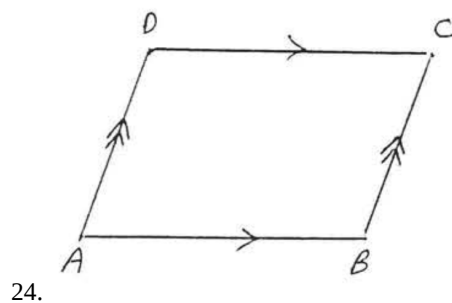
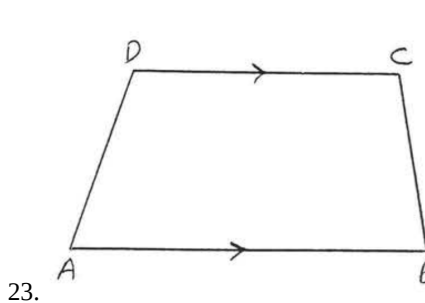
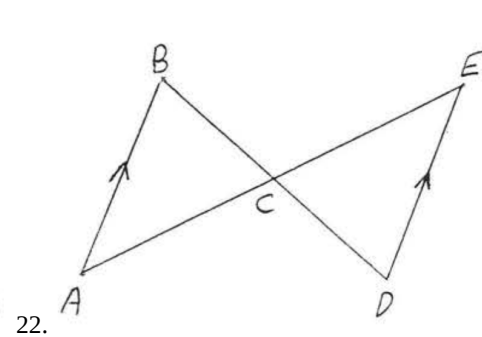
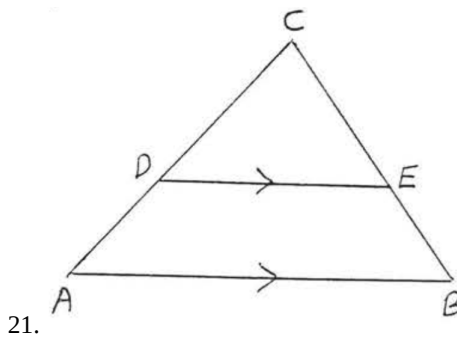
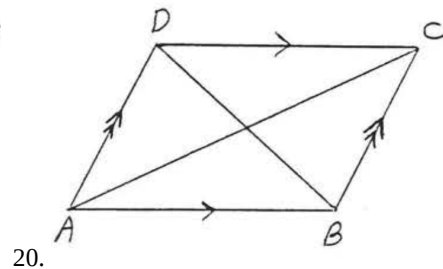
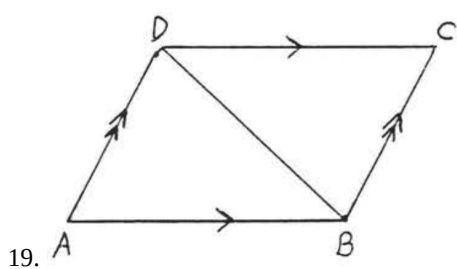
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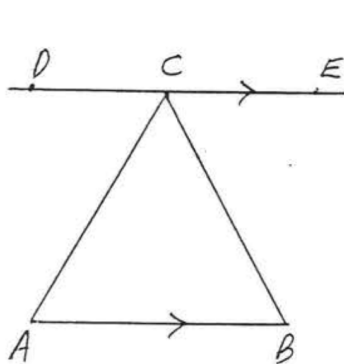


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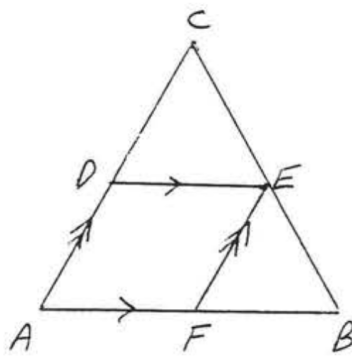


19 - 26. For each of the following, list all pairs of alternate interior angles and corresponding angles. If there are none, then list all pairs of interior angles on the same side of the transversal. Indicate the parallel lines which form each pair of angles.



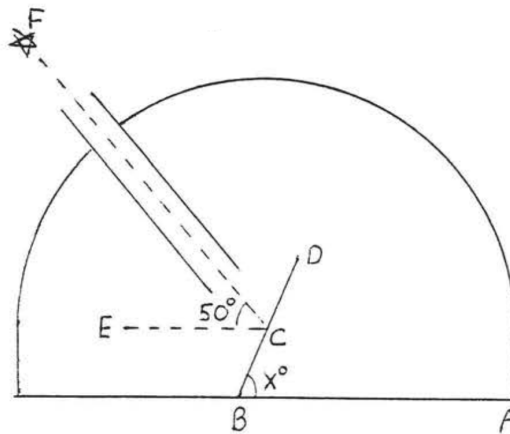


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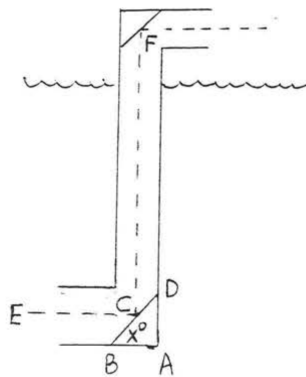


26.

27. A telescope is pointed at a star 50° above the horizon. What angle x° must the mirror BD make with the horizontal so that the star can be seen in the eyepiece E ?



28. A periscope is used by sailors in a submarine to see objects on the surface of the water. If $\angle ECF = 90^\circ$, what angle x° does the mirror BD make with the horizontal?



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