UNIT THREE

Angles

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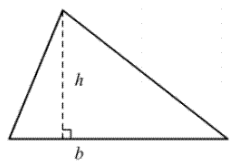
Important Terms and Terminology

Acute Triangle: A triangle in which each of the three interior angles measures less than 90°.

Altitude: A line segment giving the height of a geometric figure. In a triangle, an altitude is found by drawing the perpendicular from a vertex to the side opposite.



Congruence: The property of being congruent. Two geometric shapes are congruent if they are equal in all respects.

Diagonal: In a polygon, a line segment joining two vertices that are not next to each other (i.e., not joined by one side).

Polygon: A closed figure formed by three of more line segments. Examples of polygons are triangles, quadrilaterals, pentagons and octagons.

Prism: A three dimensional figure with two parallel, congruent polygonal bases. A prism is named by the shape of its bases. For example, rectangular prism, triangular prism.

Pythagorean Theorem: The conclusion that, in a right triangle, the square of the length of the longest side is equal to the sum of the squares of the lengths of the other two sides (legs).

Quadrilateral: A polygon with four sides.

Regular: A shape is said to be regular if all its sides are equal (i.e. square, equilateral triangle) and all its angles are equal.

Right Triangle: A triangle containing one 90° angle.

Similar Triangles: Triangles in which corresponding sides are proportional.

Problem Solving Strategy
The Five-Step Process

LIST:	List all known and unknown variables in your problem.
FORMULA(E):	State any useful formulae that may be of use in your problem.
ALGEBRA:	Is your unknown isolated? If not, use algebra to isolate it.
PLUG-IN	Plug in the known variables into your formula(e).
EVALUATE:	Evaluate the problem and conclude with appropriate units.

Learning Goals in this Unit

By the end of this unit, you will be able to:

- determine, through investigation using a variety of tools (e.g., dynamic geometry software, concrete materials), and describe the properties and relationships of the interior and exterior angles of triangles, quadrilaterals, and other polygons, and apply the results to problems involving the angles of polygons (***Sample problem:*** With the assistance of dynamic geometry software, determine the relationship between the sum of the interior angles of a polygon and the number of sides. Use your conclusion to determine the sum of the interior angles of a 20-sided polygon.).

- determine, through investigation using a variety of tools (e.g., dynamic geometry software, concrete materials), and describe the properties and relationships of the angles formed by parallel lines cut by a transversal, and apply the results to problems involving parallel lines (e.g., given a diagram of a rectangular gate with a supporting diagonal beam, and given the measure of one angle in the diagram, use the angle properties of triangles and parallel lines to determine the measures of the other angles in the diagram)

- create an original dynamic sketch, paperfolding design, or other illustration that incorporates some of the geometric properties from this section, or find and report on some real-life application(s) (e.g., in carpentry, sports, architecture) of the geometric properties.

Angles & Angles Theorems

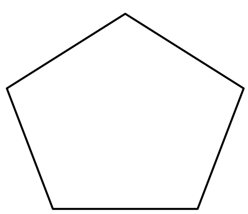
By the end of this unit, you will be able to determine, through investigation using a variety of tools (e.g., dynamic geometry software, concrete materials), and describe the properties and relationships of the interior and exterior angles of triangles, quadrilaterals, and other polygons, and apply the results to problems involving the angles of polygons.

THE SUM OF THE INTERIOR ANGLES OF A POLYGON

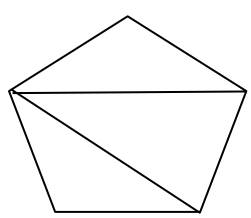
To conduct the following investigation, we will need to complete the following table:

Shape	Number of Sides	Number of Triangles	180 * Number of Triangles	Sum of the Interior Angles
Triangle	3	1	(180)(1)	180°
Quadrilateral				
Pentagon				
Hexagon				
Septagon				
Octagon				
Nonagon				
Decagon				
n - gon				

Draw the indicated shape requested in the table. In this example, we will draw the pentagon, a five sided figure.



Pick a vertex and draw lines to connect the other vertices.



Count the number of triangles. Since the sum of the interior angles in each triangle is 180° and since there are three triangles in the pentagon, we can now deduce that the sum of the interior angles of a pentagon is:

Sum of the interior angles of pentagon = (3 triangles)(180°)
= 540°

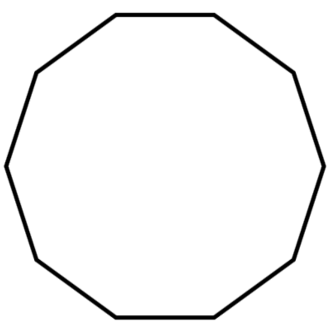
Conclusion:

Shape	Number of Sides	Number of Triangles	180 * Number of Triangles	Sum of the Angles
Triangle	3	1	(180)(1)	180°
Quadrilateral	4	2	(180)(2)	360°
Pentagon	5	3	(180)(3)	540°
Hexagon	6	4	(180)(4)	720°
Septagon	7	5	(180)(5)	900°
Octagon	8	6	(180)(6)	1080°
Nonagon	9	7	(180)(7)	1260°
Decagon	10	8	(180)(8)	1440°
n – gon	**N**	**n – 2**	**180(n-2)**	**180n – 360°**

In essence, note that every single shape contains a number of triangles as illustrated in the investigation. Note that the number of triangles always equals two less than the number of sides. Since every triangle contains 180°, we can deduce that an n-sided shape contains (n-2) triangles. When we multiply the number of triangles by 180°, we get the sum of the angles in that shape.

Sample problem: Determine the sum of the interior angles of a 20-sided polygon.

Given a *regular* decagon, determine the measure of each angle.



Note: You can find the meaning of the word regular in Important Terms & Terminology.

Challenging Example:

Given that the sum of the interior angles of an n-sided polygon is 4860°, how many sides does this shape have?

Sample problem: Determine the sum of the interior angles of a 20-sided polygon.

Solution:

LIST: n = 20 sides

FORMULA(E): $Number_{triangles} = n – 2$ & $Sum_{InteriorAngles} = 180(n-2)$

ALGEBRA: **None required here**

PLUG-IN:
$Number_{triangles} = n – 2$
$Number_{triangles} = (20) – 2$
$Number_{triangles} = 18$ triangles

$Sum_{InteriorAngles} = 180(18)$

EVALUATE: $Sum_{InteriorAngles} = 3240°$

The sum of the Interior Angles of a 20-sided polygon is 3240°.

Given a regular decagon, determine the measure of each angle.

Solution:

LIST: deca is the Latin prefix for 10, hence n = 10 sides

FORMULA(E): $Number_{triangles} = n – 2$ & $Sum_{InteriorAngles} = 180(n-2)$

ALGEBRA: **None initially**

PLUG-IN:
$Number_{triangles} = n – 2$
$Number_{triangles} = (10) – 2$
$Number_{triangles} = 8$ triangles

$Sum_{InteriorAngles} = 180(8)$

EVALUATE: $Sum_{InteriorAngles} = 1440°$

However, since this is a *regular* decagon, all sides are equal therefore

Each Interior Angle = $\frac{Sum\ of\ the\ Interior\ Angles}{Number\ of\ Angles}$

Each Interior Angle = $\frac{1440°}{10}$

Each Interior Angle = 144°

Challenging Example:

Given that the sum of the interior angles of an n-sided polygon is 4860°, how many sides does this shape have?

Solution:

LIST: $Sum_{InteriorAngles}$ = 4860°

FORMULA(E): $Number_{triangles}$ = n – 2 & $Sum_{InteriorAngles}$ = 180(n-2)

ALGEBRA: We will have to solve for $Number_{triangles}$ = n – 2 and then n itself.

$Sum_{InteriorAngles}$ = 180(n-2)

180(n-2) = $Sum_{InteriorAngles}$

180(n-2) = 4860

$$\frac{180(n-2)}{180} = \frac{4860}{180}$$

n-2 = 27 27 represents the number of triangles

n-2 + 2 = 27 + 2

EVALUATE: n = 29 sides

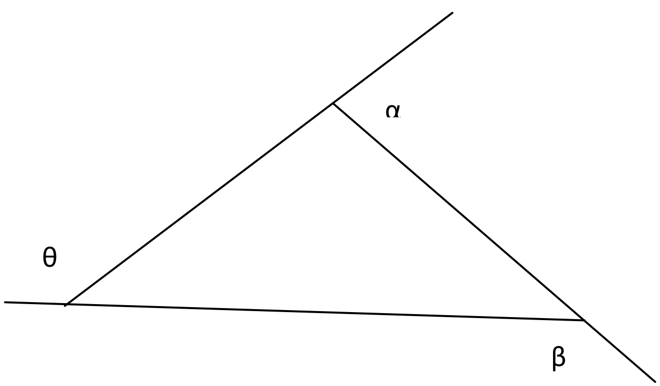
Hence, if the sum of the interior angles of an n-sided polygon is 4860°, then it must have 29 sides.

THE SUM OF THE EXTERIOR ANGLES OF A POLYGON

To conduct the following investigation, we will need to complete the following table:

Shape	**Number of Sides**	**Sum of the Exterior Angles**
Triangle	3	360°
Quadrilateral		
Pentagon		
Hexagon		
Septagon		
Octagon		
Nonagon		
Decagon		
n – gon		

Draw the indicated shape requested in the table. In this example, we will draw the triangle, a three sided figure with extended side lengths. We then label and measure each **exterior** angle.



Once you have finished measuring each exterior angle, add them all together. You will have found the sum of the exterior angles of triangle.

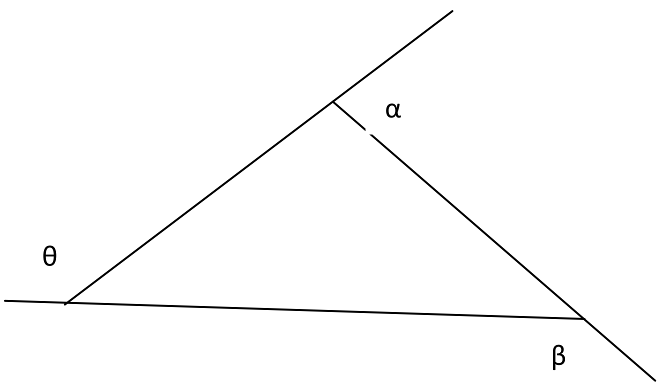
$$\alpha + \beta + \theta = 360°$$

Note: Since this is an experiment, your summation result will only be as close as the accuracy of your measurements. Hence, you may not get exactly 360°.

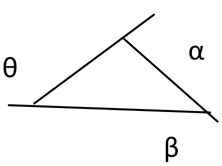
Conclusion:

Shape	Number of Sides	Sum of the Exterior Angles
Triangle	3	360°
Quadrilateral	4	360°
Pentagon	5	360°
Hexagon	6	360°
Septagon	7	360°
Octagon	8	360°
Nonagon	9	360°
Decagon	10	360°
n – gon	**N**	360°

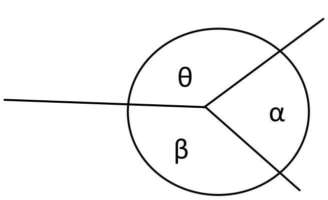
In essence, no matter how many sides the polygon has, the sum of the exterior angles will always equal zero. Here is an illustrated explanation why this is true.



What would happen if all the side lengths were shortened proportionately (meaning the sides lengths change such that the angles do not) while keeping the extensions.

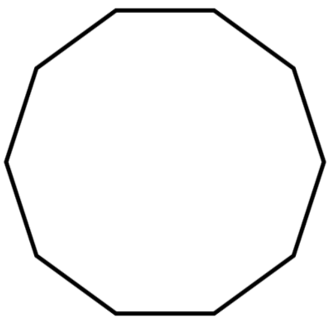


Continuing this process, we eventually get sides lengths of zero (leaving only the extensions) and the angles all converge to a single point. Also note that we can draw a circle to confirm that this sums up to 360°.



Sample problem: Determine the sum of the exterior angles of a 20-sided polygon.

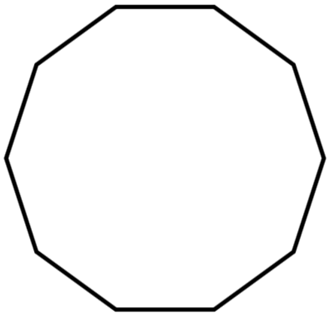
Given a *<u>regular</u>* decagon, determine the measure of each exterior angle.



Sample problem: Determine the sum of the exterior angles of a 20-sided polygon.

From our conclusions within the experiment on the sum of the exterior angles of any polygon, we know that the sum will be 360° for a 20-sided polygon.

Given a *regular* decagon, determine the measure of each exterior angle.



Solution:

LIST: Again, from our conclusions in the previous experiment, we know that the sum of the exterior angles of a decagon will be 360°.

FORMULA(E): Each Exterior Angle = $\frac{Sum\ of\ the\ Exterior\ Angles}{Number\ of\ Angles}$

ALGEBRA: **None**

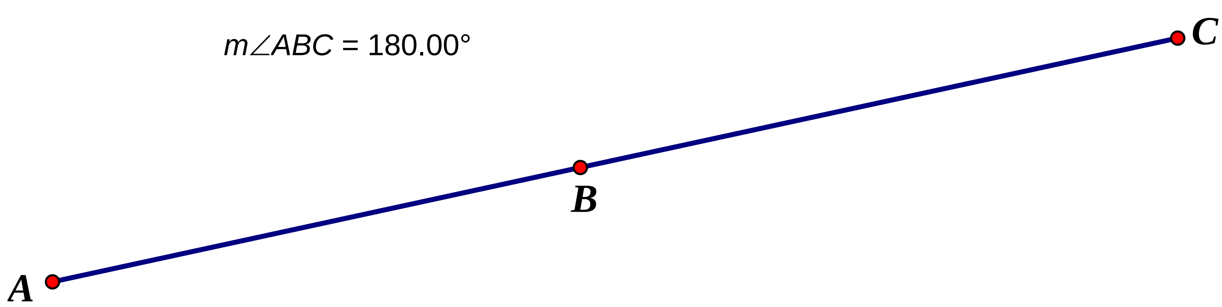
PLUG-IN: Each Exterior Angle = $\frac{360°}{10}$

EVALUATE: Each Exterior Angle = 36°

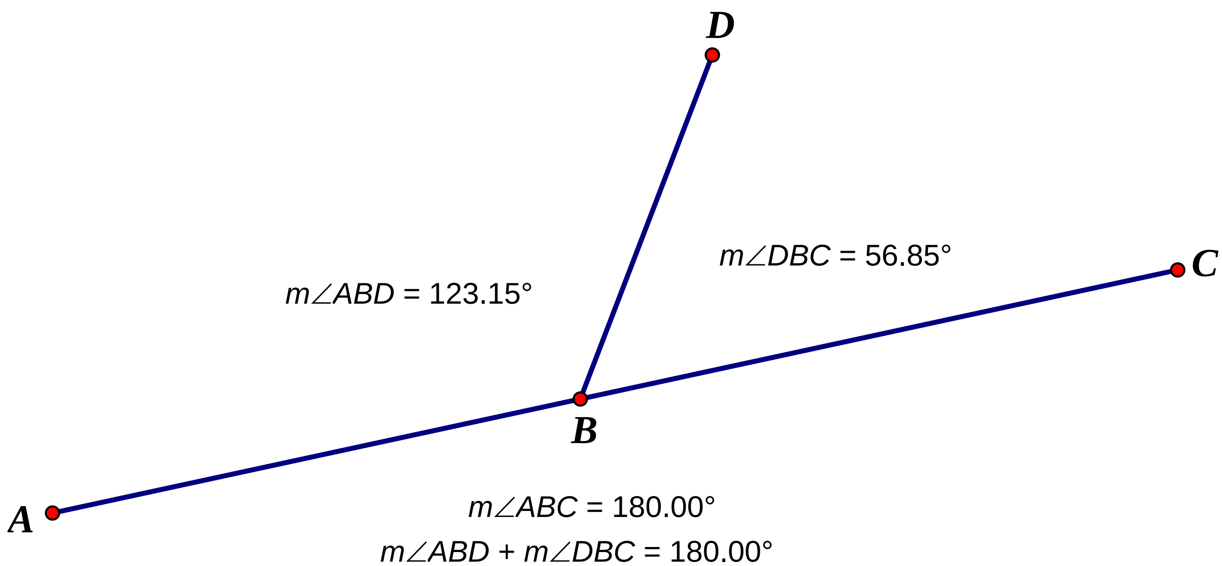
By the end of this class you will be able to determine, through investigation using a variety of tools (e.g., dynamic geometry software, concrete materials), and describe the properties and relationships of the angles formed by parallel lines cut by a transversal, and apply the results to problems involving parallel lines (e.g., given a diagram of a rectangular gate with a supporting diagonal beam, and given the measure of one angle in the diagram, use the angle properties of triangles and parallel lines to determine the measures of the other angles in the diagram).

Basic Concepts

Before we begin looking at parallel lines, let us review some basic concepts regarding angles. First, the angle of a line is simply 180°. In the GSP diagram below, angle ABC is constructed from a line segment AC, Hence the measure of angle ABC is 180°.



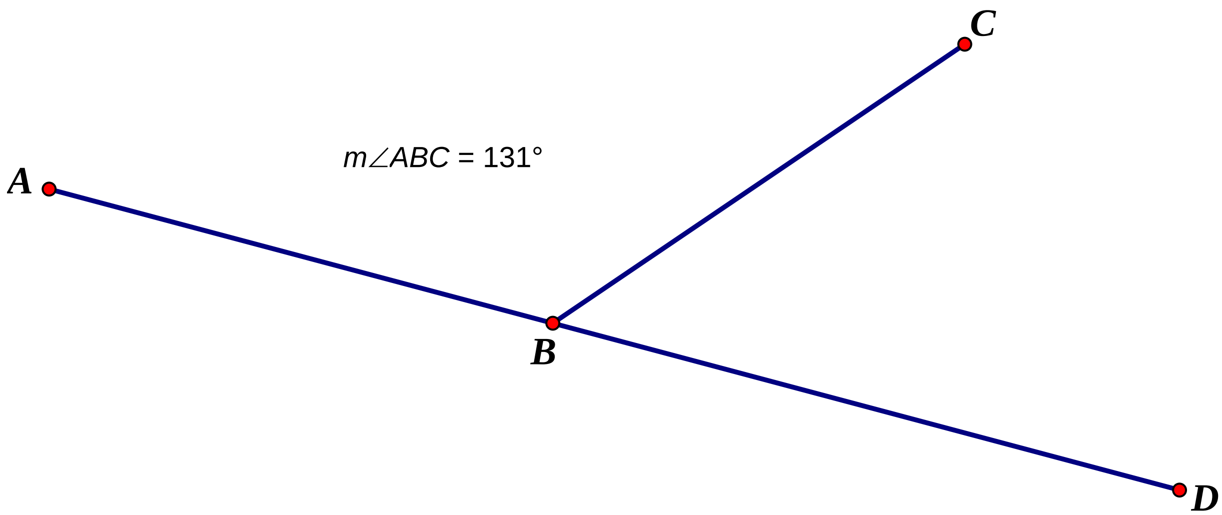
Now let us introduce a line segment BD that begins at B and extends anywhere between points A and C. Note from the GSP diagram below that the angle ABD + angle DBC equal 180°. These angles are called **supplementary angles.**



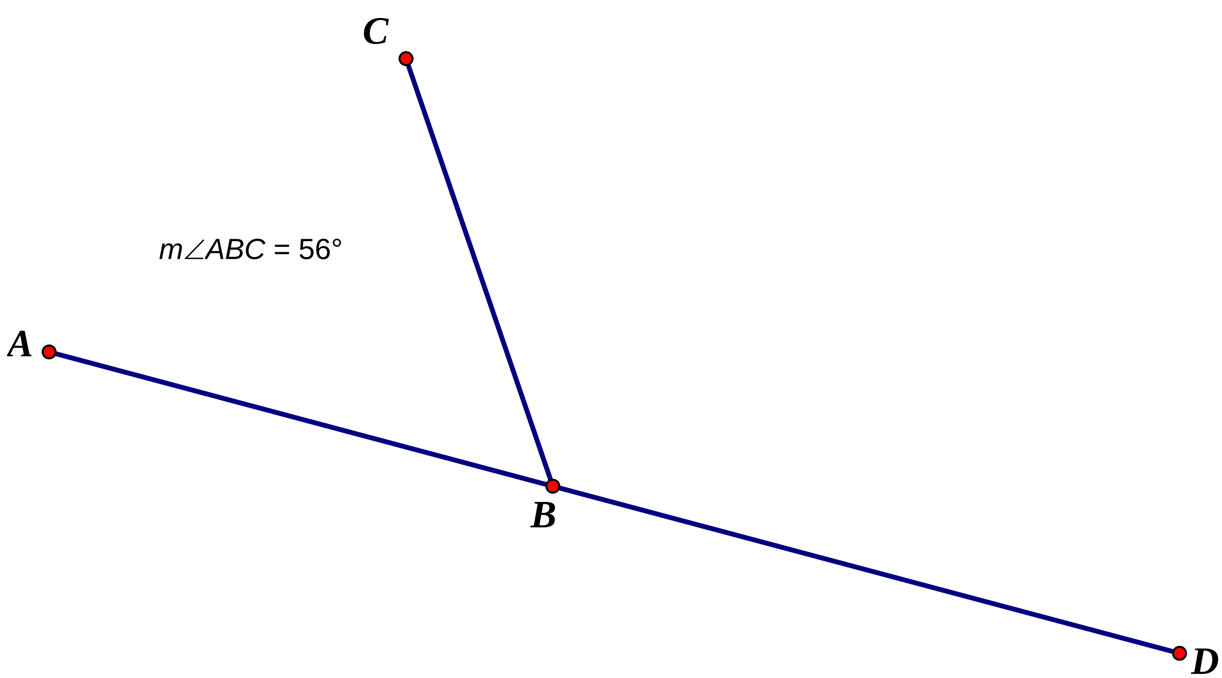
NOTE: GSP refers to Geometer's Sketchpad which is the software used to create the diagrams.

Example:

Given the GSP diagram below, find the measure of the missing angle.

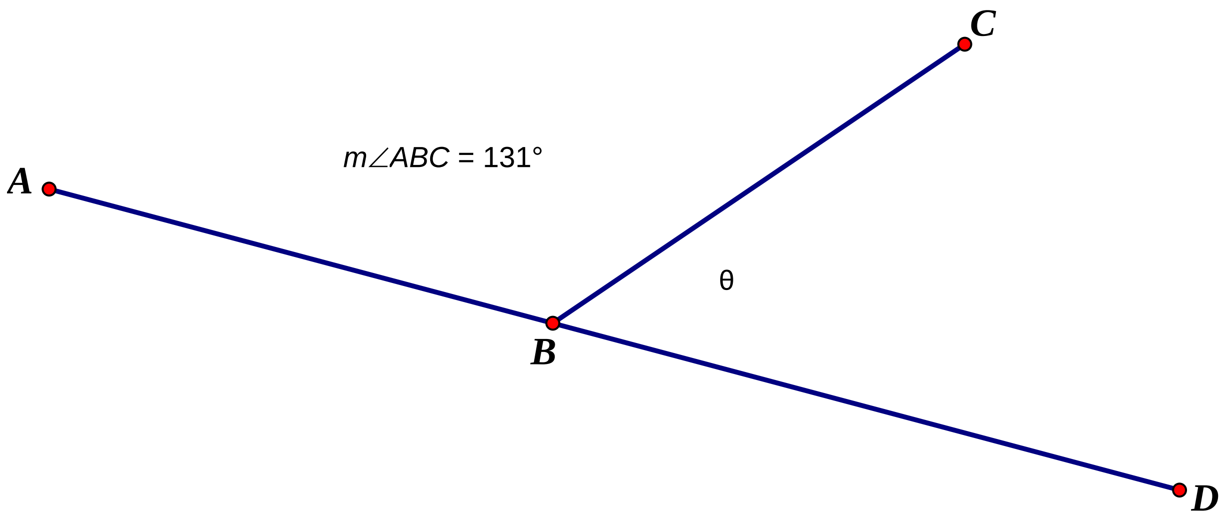


Given the GSP diagram below, find the measure of the missing angle.



Example:

Given the GSP diagram below, find the measure of the missing angle.



LIST: Another way to refer to angle ABC is to name it using an unknown variable. In geometry, we typically use Greek letters to represent unknown angles. In this case, angle ABC will be $\beta = 131°$. Note β is the Greek letter beta. The unknown variable will be theta, θ.

FORMULA(E): By supplementary angles $\beta + \theta = 180°$

ALGEBRA: **We need to isolate theta, θ.**

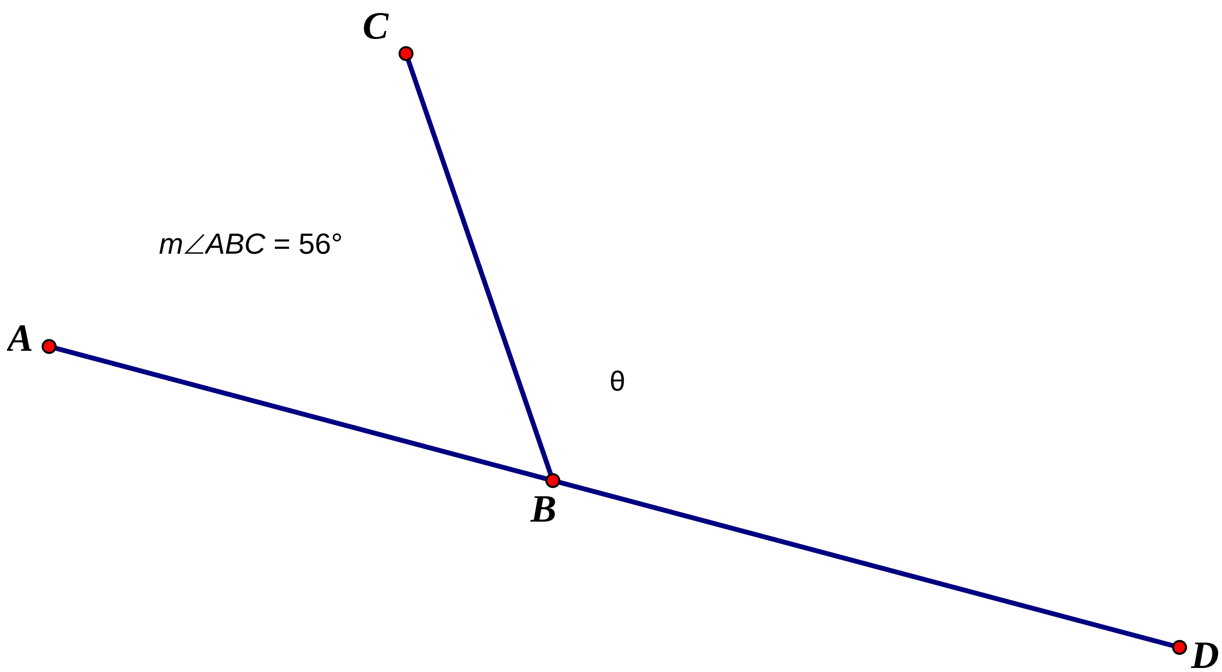
$\beta + \theta - \beta = 180 - \beta$
$\theta = 180 - \beta$

PLUG-IN: $\theta = 180 - 131$

EVALUATE: $\theta = 49°$

A quick review of the number tells you that the answer is correct. The value of the angle is less than 90° which matches the acute angle which we expected in the diagram.

Given the GSP diagram below, find the measure of the missing angle.



LIST: Let alpha, $\alpha = 56°$ and the unknown variable be theta, θ.

FORMULA(E): By supplementary angles $\alpha + \theta = 180°$

ALGEBRA: **We need to isolate theta, θ.**

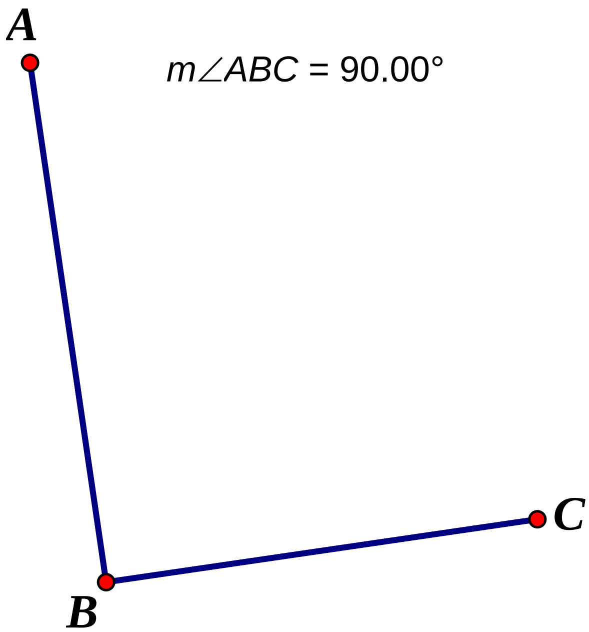
$\alpha + \theta - \alpha = 180 - \alpha$
$\theta = 180 - \alpha$

PLUG-IN: $\theta = 180 - 56$

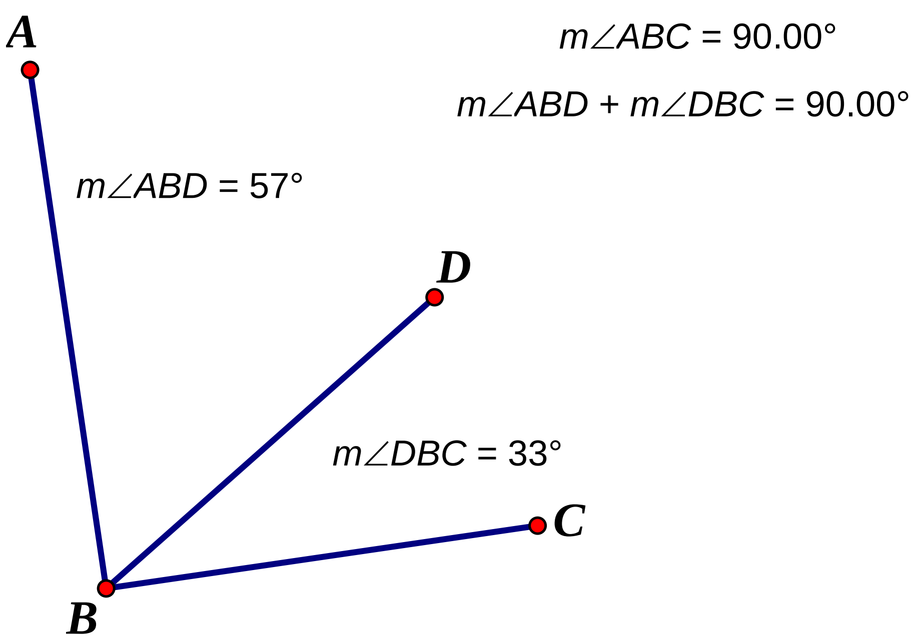
EVALUATE: $\theta = 124°$

Again, the answer makes numerical sense since it is superior (or greater than 90°). From the diagram above, we were expecting an obtuse angle.

Now let us look at a scenario where instead of cutting a line, we cut a right angle. Note the GSP diagram below of a right angle which illustrates that the angle ABC is 90°.

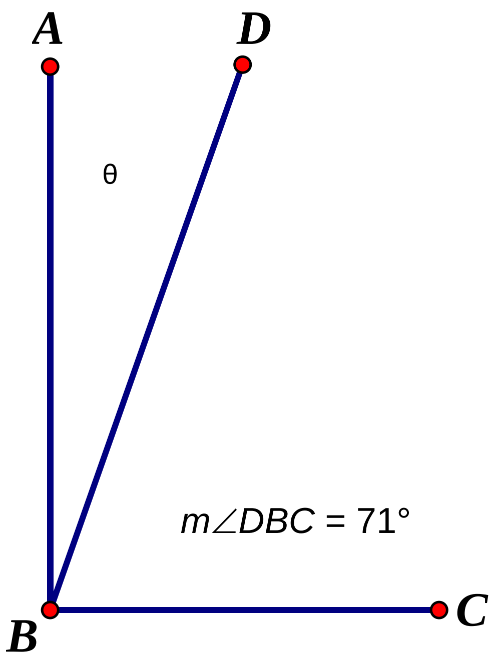


As we did in the previous concept, let us introduce a line segment (starting at B) which cuts this 90° angle into two separate angles. Note from the GSP diagram below that angle ABD and angle DBC still equal 90°. These angles are called **<u>complementary angles.</u>**

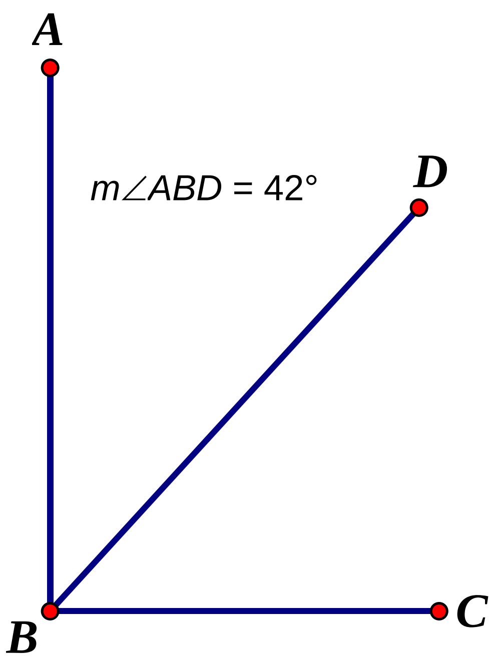


Example:

Given the GSP diagram below, find the measure of the missing angle.

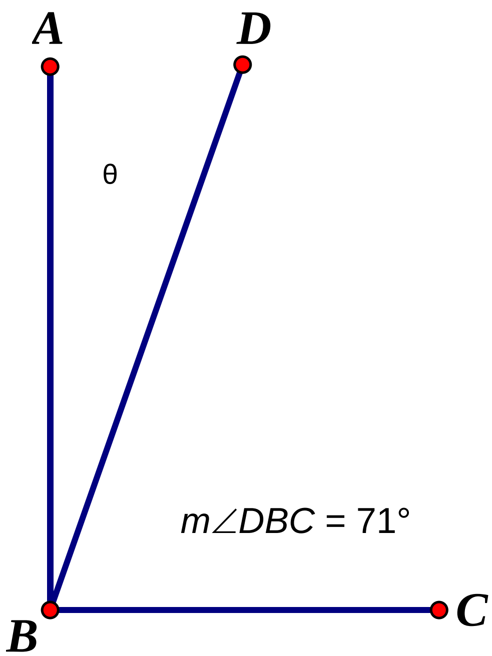


Given the GSP diagram below, find the measure of the missing angle.



Example:

Given the GSP diagram below, find the measure of the missing angle.



LIST: Let angle DBC be $\alpha = 71°$ and the unknown variable be theta, θ.

FORMULA(E): By complementary angles $\alpha + \theta = 90°$

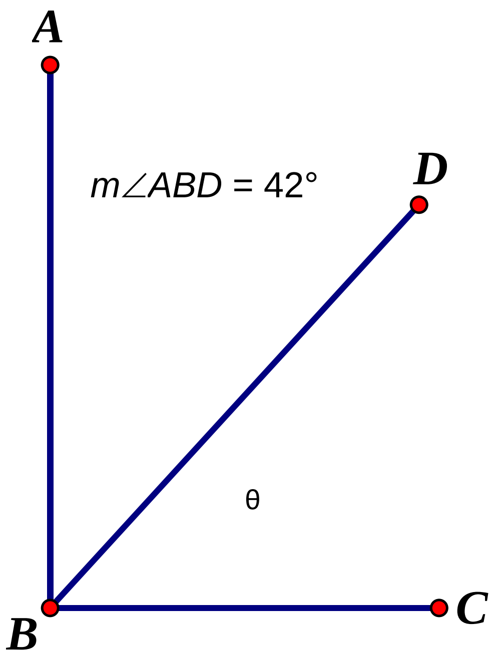
ALGEBRA: **We need to isolate theta, θ.**

$\alpha + \theta - \alpha = 90 - \alpha$
$\theta = 90 - \alpha$

PLUG-IN: $\theta = 90 - 71$

EVALUATE: $\theta = 19°$

Given the GSP diagram below, find the measure of the missing angle.



LIST: Let angle ABD be $\alpha = 42°$ and the unknown variable be theta, θ.

FORMULA(E): By complementary angles $\alpha + \theta = 90°$

ALGEBRA: **We need to isolate theta, θ.**

$\alpha + \theta - \alpha = 90 - \alpha$
$\theta = 90 - \alpha$

PLUG-IN: $\theta = 90 - 42$

EVALUATE: $\theta = 48°$

Sum of the Interior Angles of a Triangle Theorem

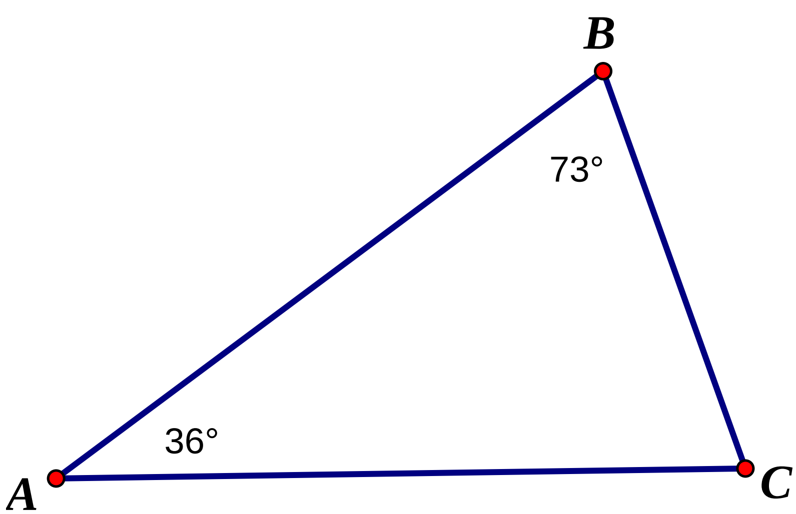
Another basic concept is the sum of the interior angles of a triangle. From the experiment we did previously with polygons, we saw that the sum of the interior angles of a triangle is 180°.

This means that given three angles, say α, β and θ, that:

$$\alpha + \beta + \theta = 180°$$

by the **Sum of the Interior Angles of a Triangle Theorem**.

Now look at the GSP diagram below and let's find the missing angle using that information.



LIST: Let $\alpha = 36°$, $\beta = 73°$ and $\theta = ?$

FORMULA(E): By the sum of the interior angles of a triangle theorem: $\alpha + \beta + \theta = 180°$

ALGEBRA: **We need to isolate theta, θ.**

$\alpha + \beta + \theta - \alpha - \beta = 180° - \alpha - \beta$

$\theta = 180° - \alpha - \beta$

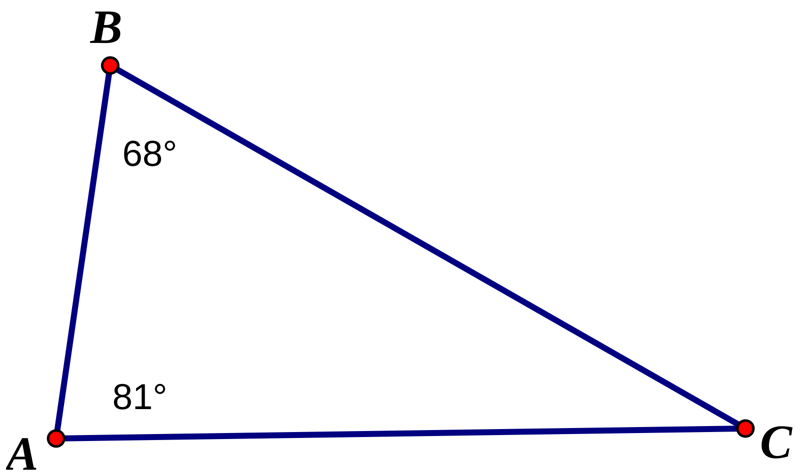
PLUG-IN: $\theta = 180° - 36 - 73$

$\theta = 180° - 109$

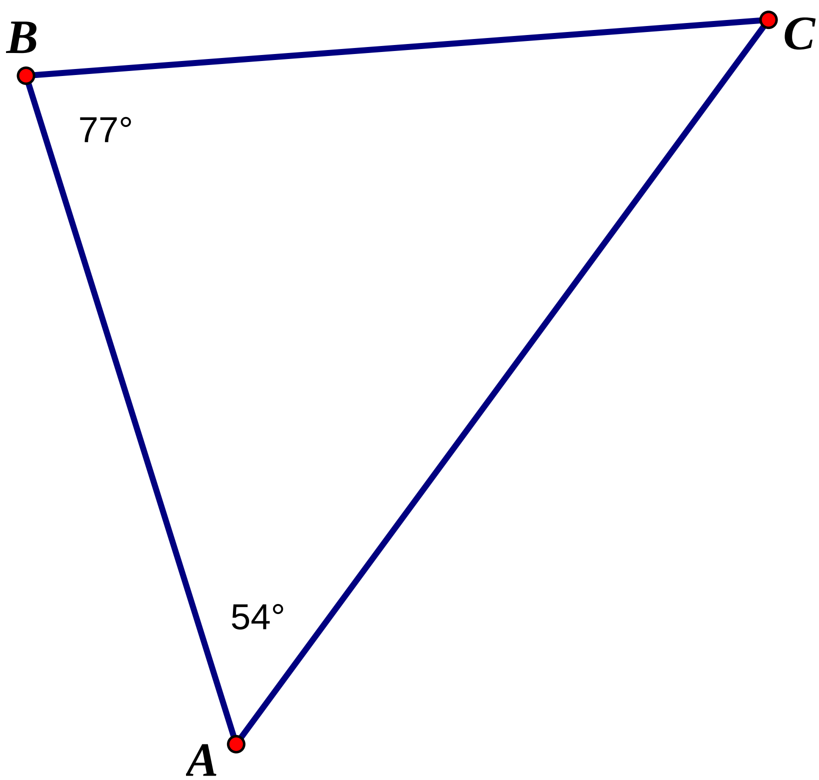
EVALUATE: $\theta = 71°$

Example:

Given the GSP diagram below, find the measure of the missing angle.

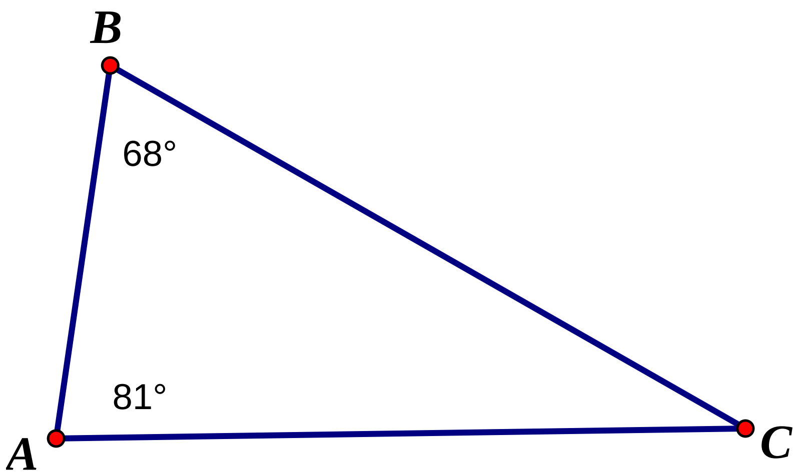


Given the GSP diagram below, find the measure of the missing angle.



Example:

Given the GSP diagram below, find the measure of the missing angle.



LIST: Let $\alpha = 81°$, $\beta = 68°$ and $\theta = ?$

FORMULA(E): By the sum of the interior angles of a triangle theorem: $\alpha + \beta + \theta = 180°$

ALGEBRA: **We need to isolate theta, θ.**

$\alpha + \beta + \theta - \alpha - \beta = 180° - \alpha - \beta$

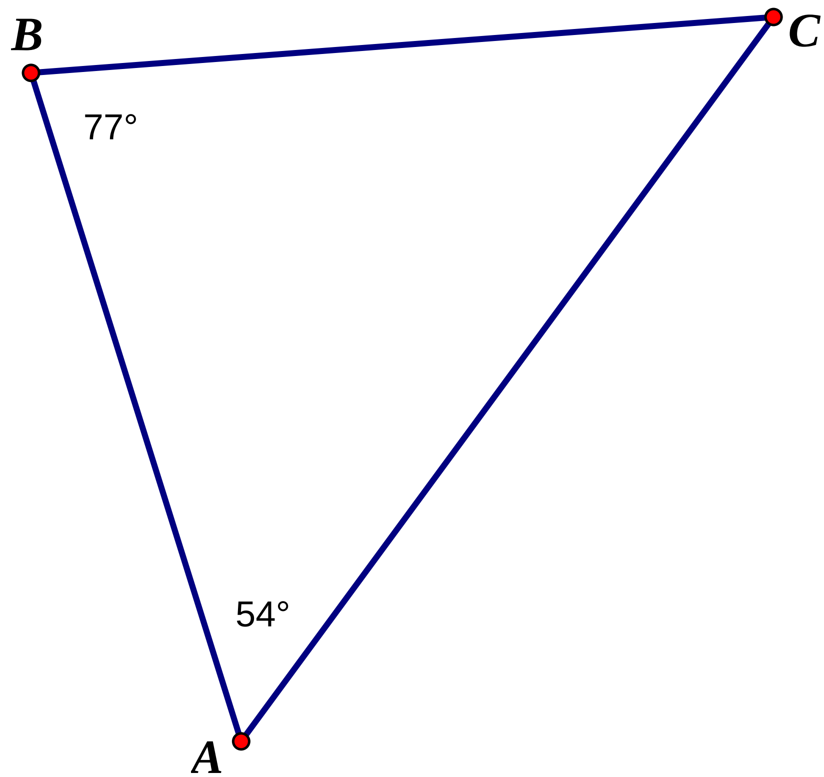
$\theta = 180° - \alpha - \beta$

PLUG-IN: $\theta = 180° - 81 - 68$

$\theta = 180° - 149$

EVALUATE: $\theta = 31°$

Given the GSP diagram below, find the measure of the missing angle.



LIST: Let $\alpha = 54°$, $\beta = 77°$ and $\theta = ?$

FORMULA(E): By the sum of the interior angles of a triangle theorem: $\alpha + \beta + \theta = 180°$

ALGEBRA: **We need to isolate theta, θ.**

$\alpha + \beta + \theta - \alpha - \beta = 180° - \alpha - \beta$

$\theta = 180° - \alpha - \beta$

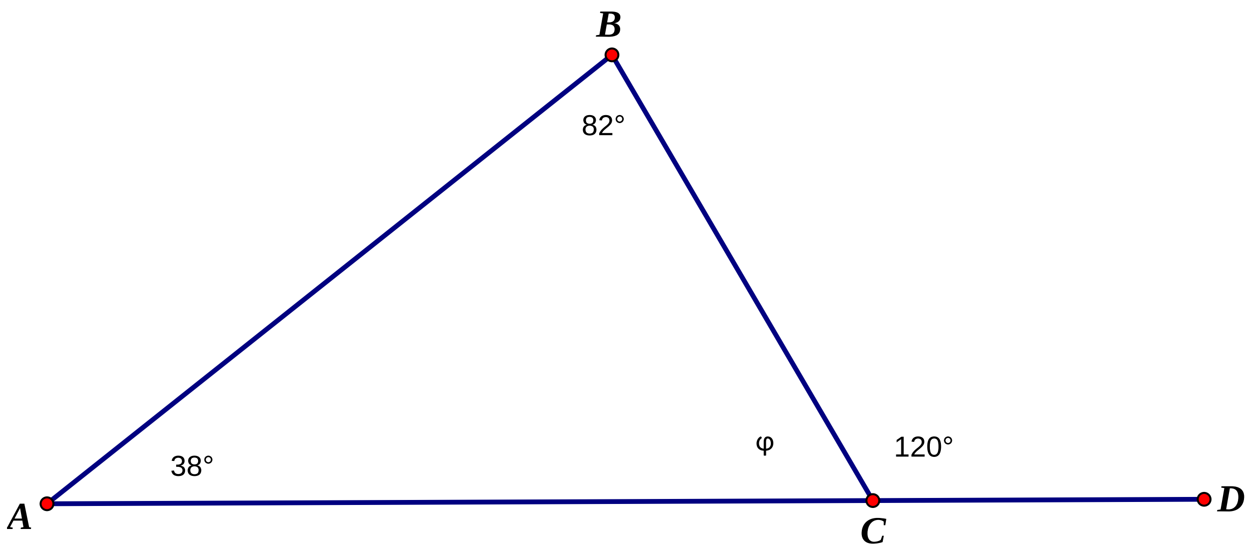
PLUG-IN: $\theta = 180° - 54 - 77$

$\theta = 180° - 131$

EVALUATE: $\theta = 49°$

Exterior Angle Theorem

An extension to the sum of the interior angles of a triangle theorem is the exterior angle theorem. As the name suggests, we can determine the angle of an exterior angle if the two non-adjacent angles are known.



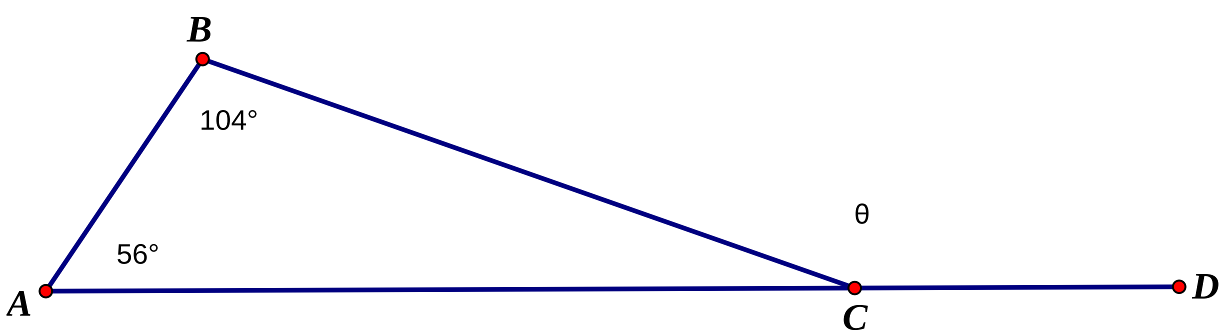
Note that $\alpha = 38°$, $\beta = 82°$ and $\theta = 120°$. In this case, we can say:

$$\alpha + \beta = \theta$$

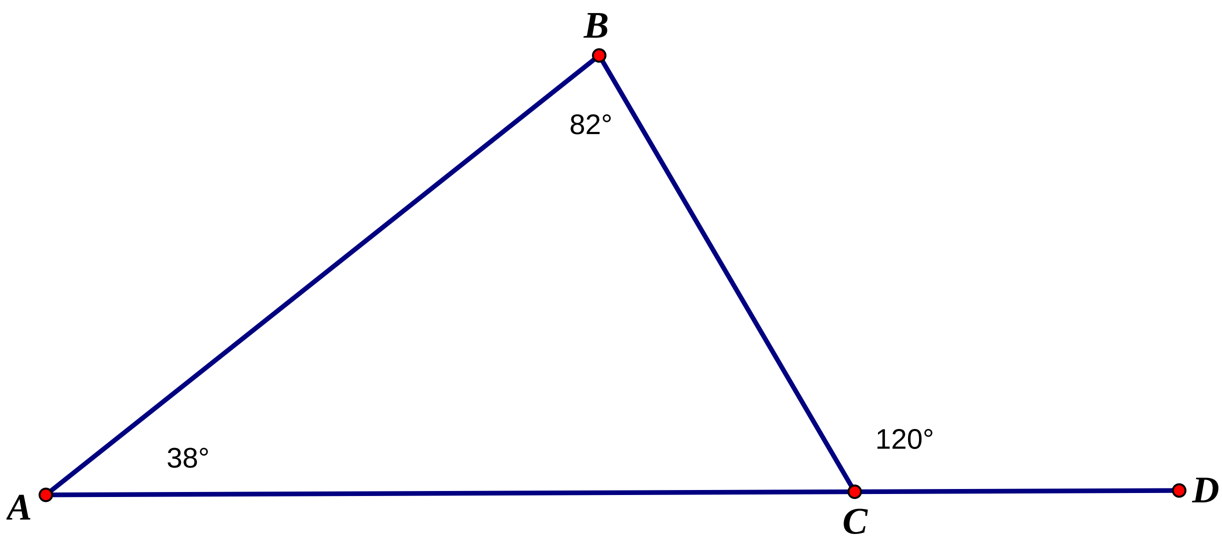
by the **Exterior Angle Theorem**.

<u>Example:</u>

Given the GSP diagram below, find the measure of the missing angle theta, θ.



Why does this work?



Note the missing angle φ ,known as phi. Notice that it is a supplementary angle with respect to the exterior angle $\theta = 120°$. Let us make a statement about this:

$$\varphi + \theta = 180°$$

Therefore:

$$\varphi + \theta - \theta = 180 - \theta$$
$$\varphi = 180 - \theta$$

Now let us make another statement using the sum of the angles in a triangle theorem.

$$\alpha + \beta + \varphi = 180°$$

Therefore:

$$\alpha + \beta + \varphi - \alpha - \beta = 180 - \alpha - \beta$$
$$\varphi = 180 - \alpha - \beta$$

If $\varphi = 180 - \theta$ and $\varphi = 180 - \alpha - \beta$, then:

$$180 - \theta = 180 - \alpha - \beta$$

Therefore;

$$180 - \theta - 180 = 180 - \alpha - \beta - 180$$

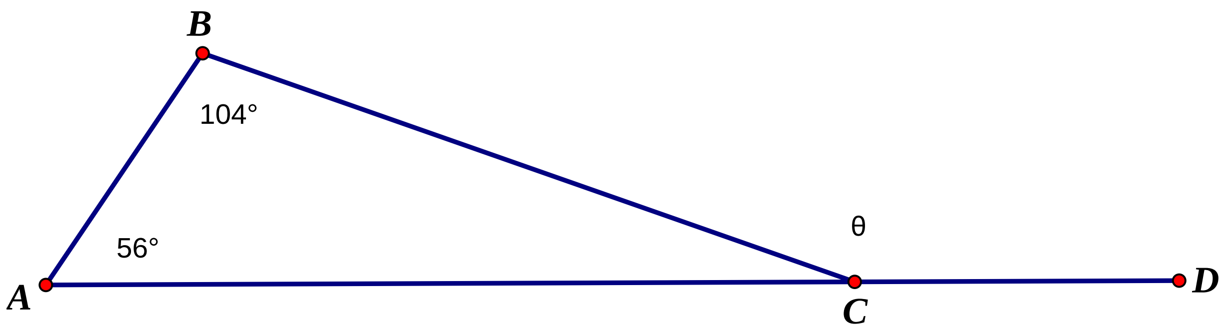
$$-\theta = -\alpha - \beta$$
$$\frac{(-\theta)}{-1} = \frac{-\alpha - \beta}{-1}$$

$$\theta = \alpha + \beta$$

Ergo the proof of the Exterior Angle Theorem.

Example:

Given the GSP diagram below, find the measure of the missing angle theta, θ.



LIST: Let $\alpha = 56°$, $\beta = 104°$ and $\theta = ?$

FORMULA(E): By the exterior angle theorem: $\alpha + \beta = \theta$

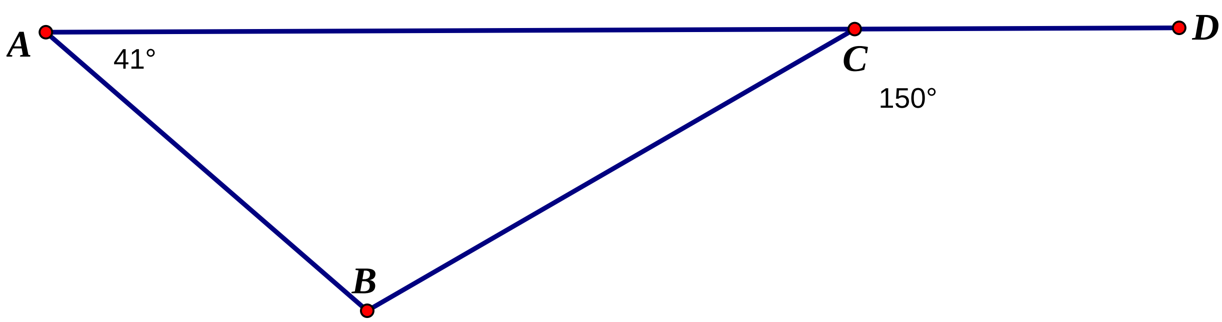
ALGEBRA: **None**

PLUG-IN: $\theta = 56 + 104$

EVALUATE: $\theta = 160°$

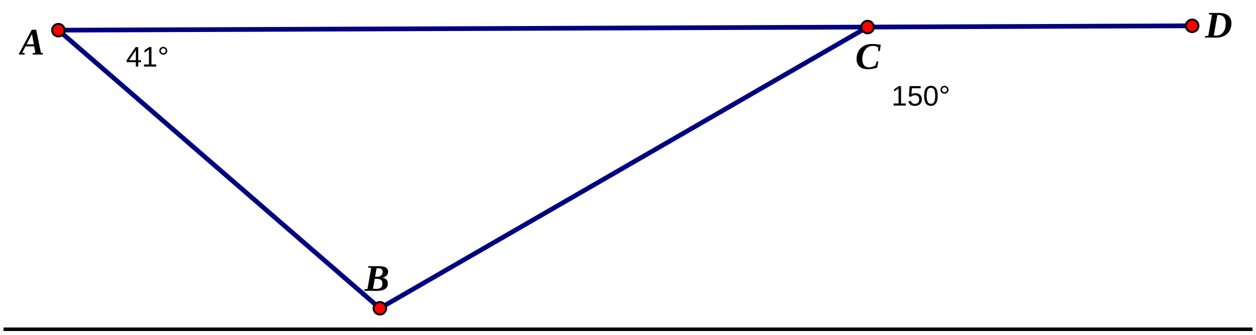
Example:

How would you solve this problem? Look at the GSP diagram below and find the missing angle β, beta.



Example:

How would you solve this problem? Look at the GSP diagram below and find the missing angle β, beta.



LIST: Let $\alpha = 41°$, $\beta = ?$ and $\theta = 150°$

FORMULA(E): By the exterior angle theorem: $\alpha + \beta = \theta$

ALGEBRA: **We need to solve for beta, β.**

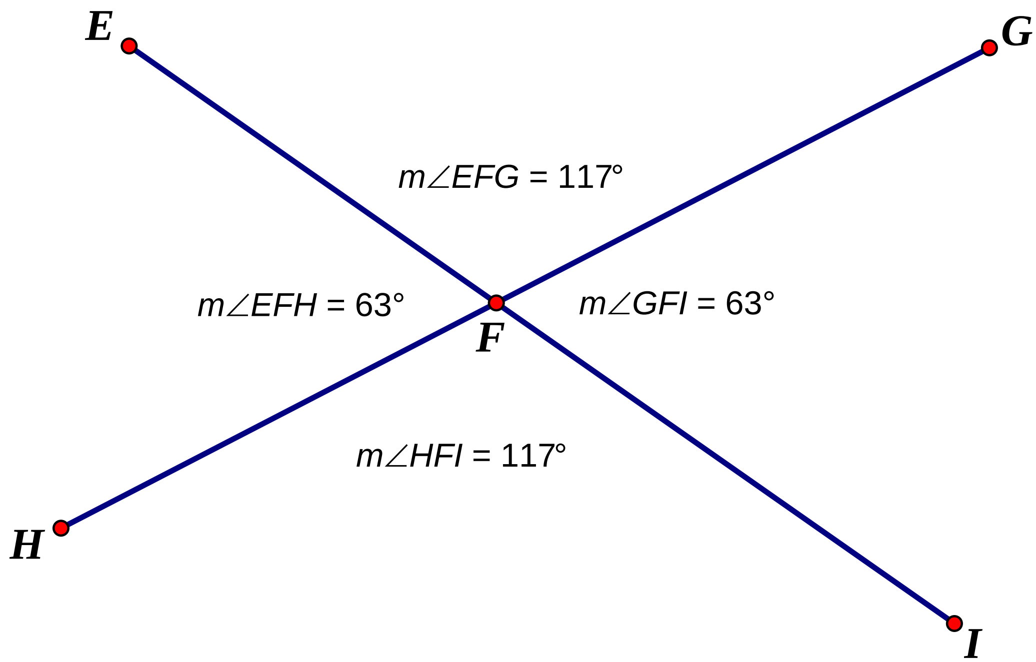
$\alpha + \beta = \theta$
$\alpha + \beta - \alpha = \theta - \alpha$
$\beta = \theta - \alpha$

PLUG-IN: $\beta = 150 - 41$

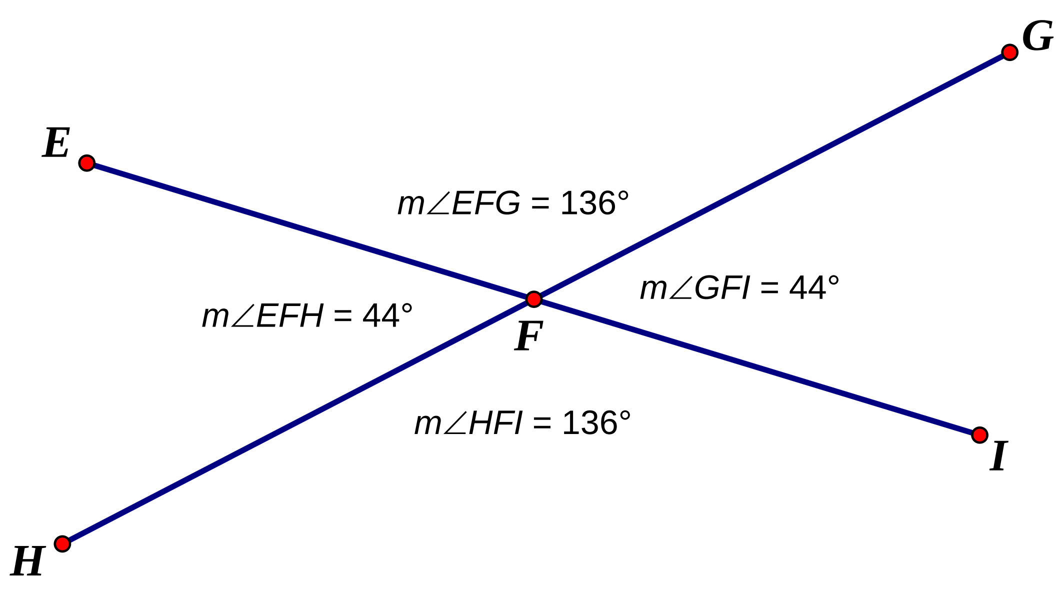
EVALUATE: $\theta = 109°$

Opposite Angle Theorem

At first, the opposite angle theorem does not appear to be an extension of a triangle property until we reflect two triangle onto one another. To begin, we will simply draw an X using GSP and analyze the four angles that have been created.



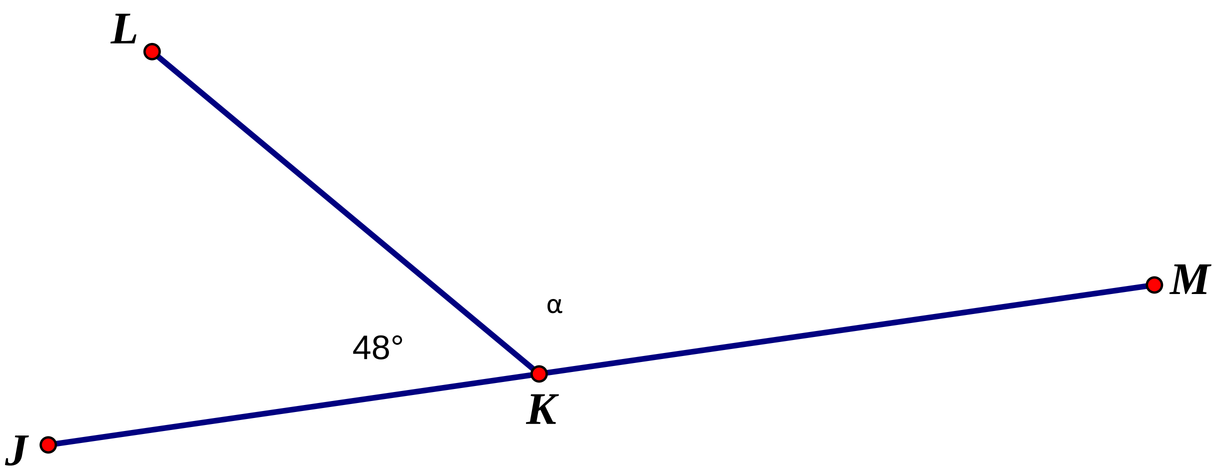
Note that the opposing angles are always equal to one another. Try this one your own. Draw an X on your paper. Measure the angles. Note that no matter how you draw the X, the opposite angles equal one another.



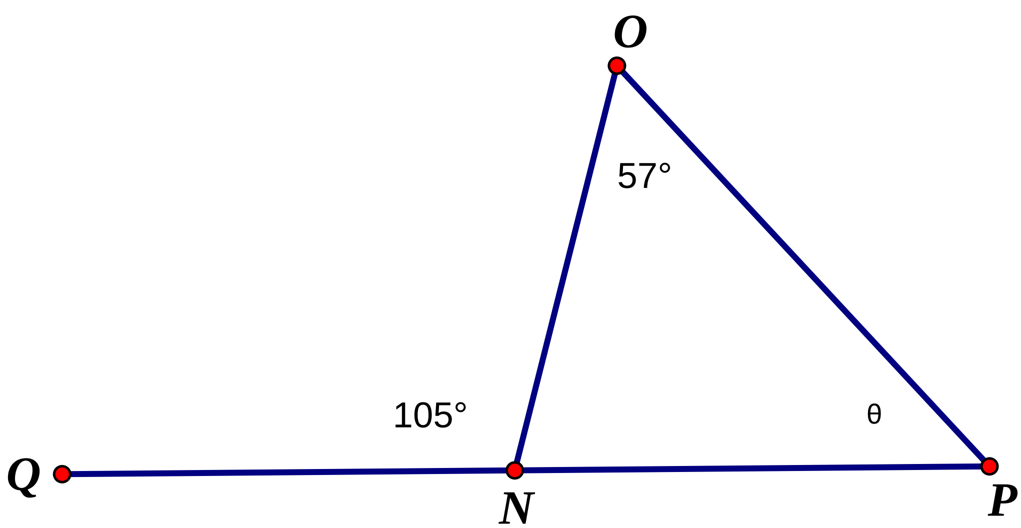
<u>**In-class task**</u> **Name: ________________**

This task is aimed at acquiring your ability to use the angle properties of triangles to determine the measures of the other angles.

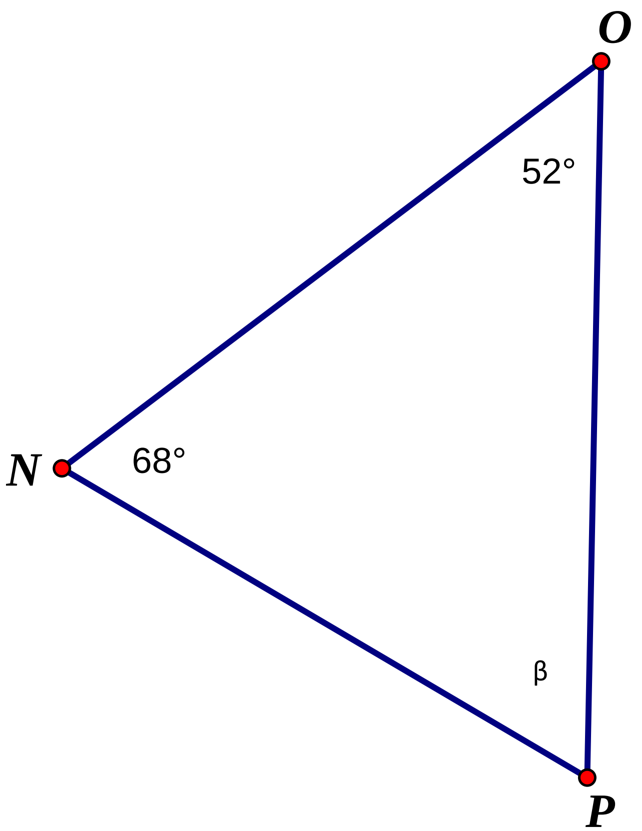
Find the missing angle in each GSP figure below. Justify your answer by stating the theorem which helped you achieve your solution. Be sure to use algebra where necessary.



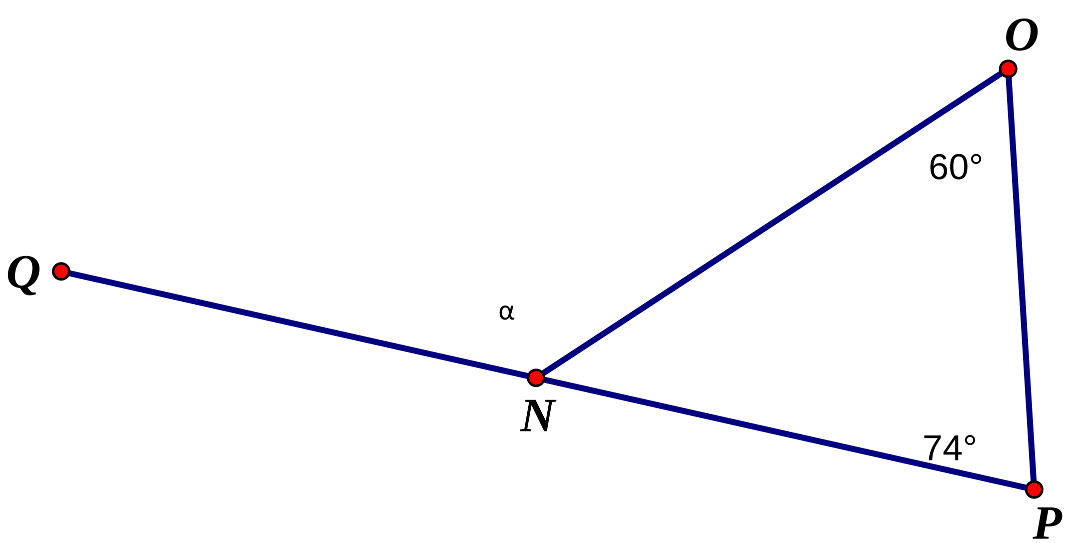
α = ______ **Justification:**



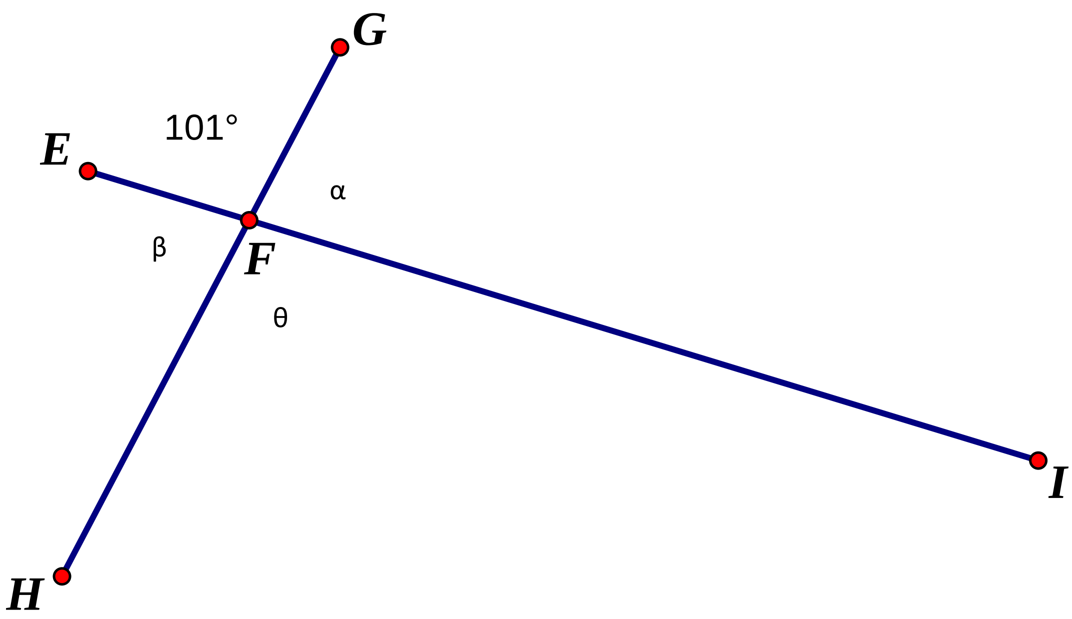
θ = ______ **Justification:**



β = ________ **Justification:**



α = ________ **Justification:**

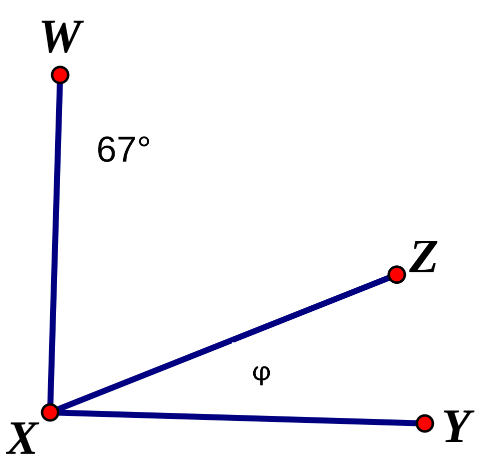


α = ________ **Justification:**

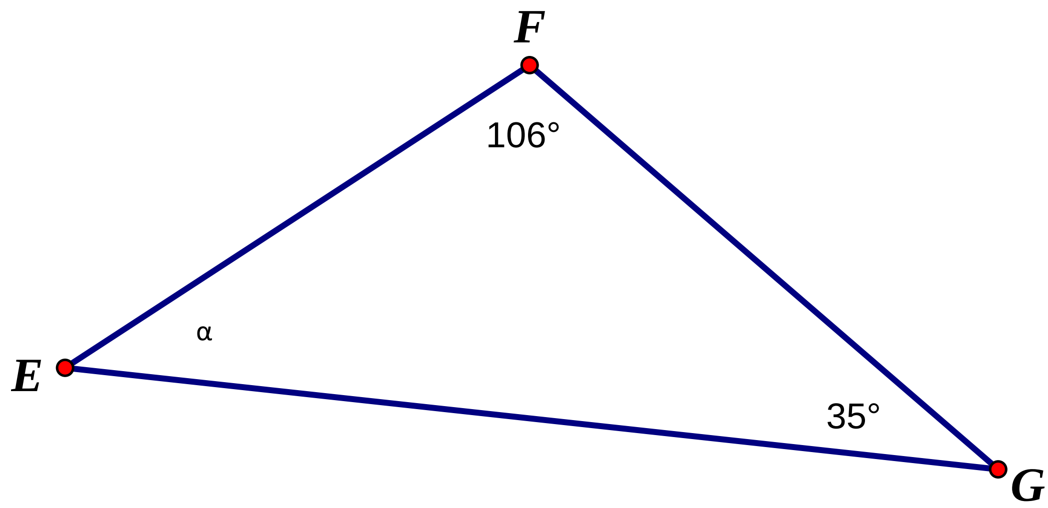
β = ________ **Justification:**

θ = ________ **Justification:**

<u>Given the right triangle WXY</u>

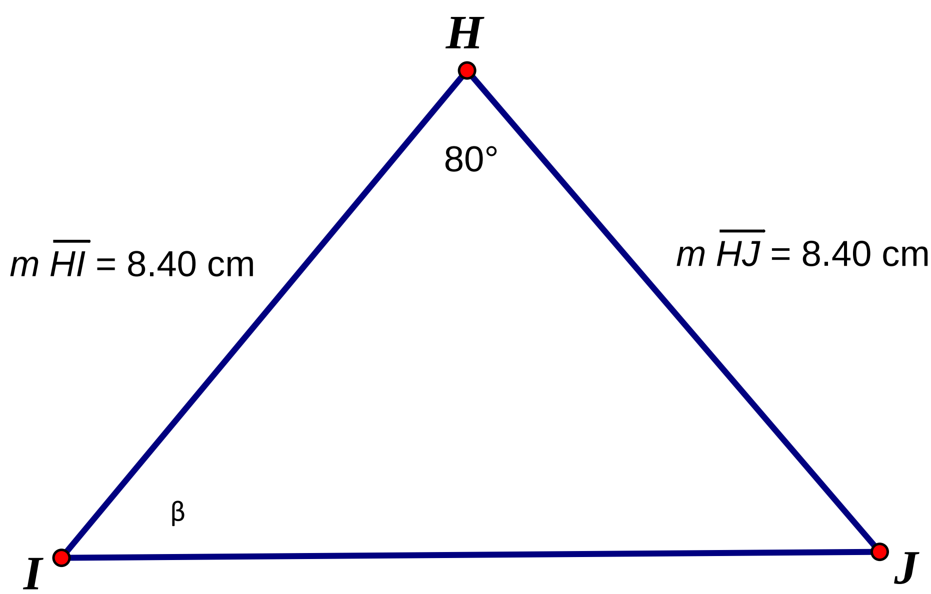


φ = ________ **Justification:**



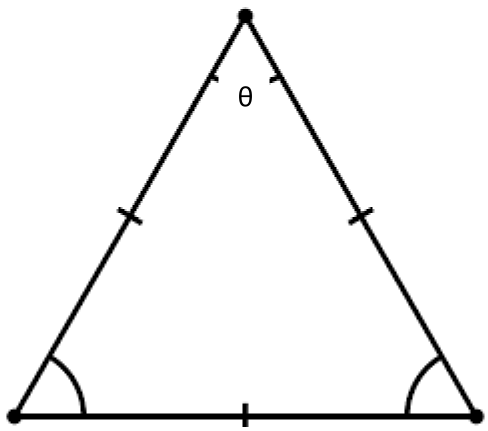
α = ________ **Justification:**

Given the isosceles triangle HIJ



β = ________ **Justification:**

<u>Given the equilateral triangle</u>

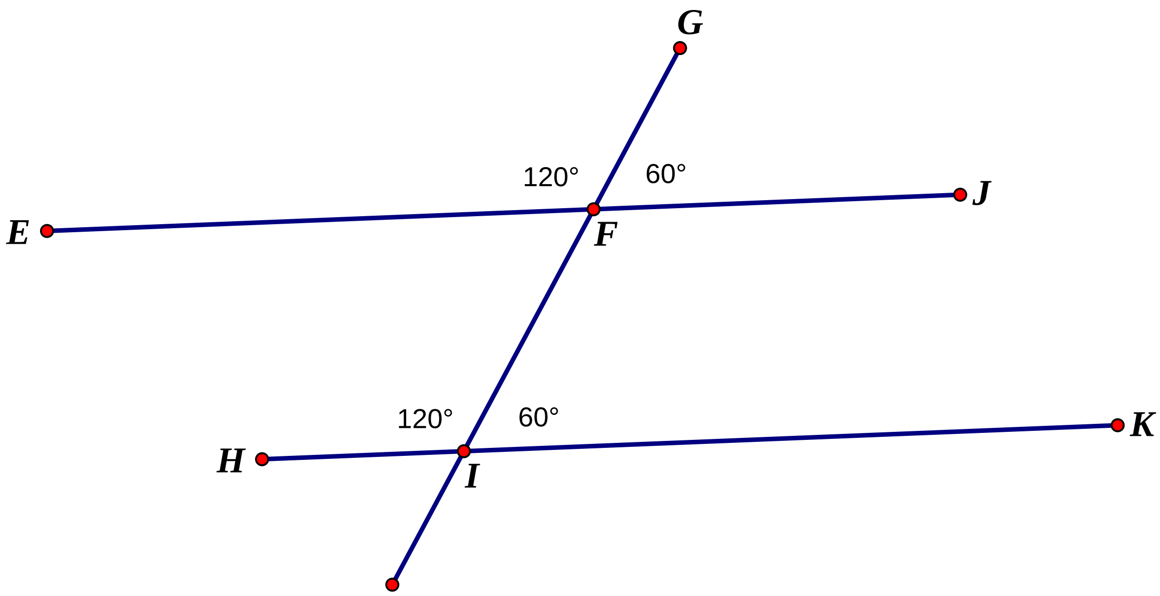


θ = ________

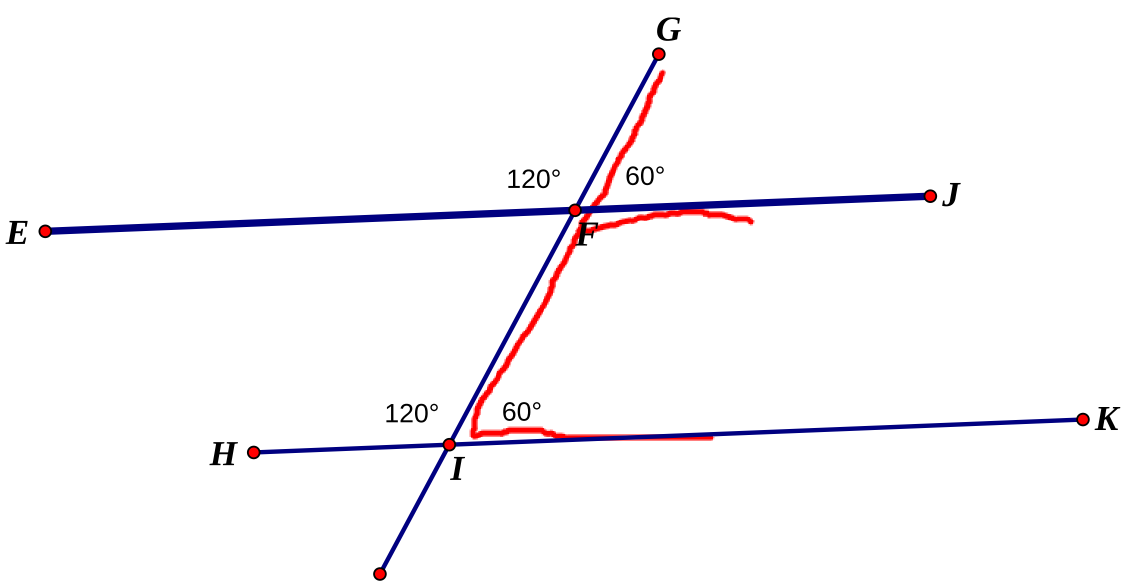
Justification:

The Parallel Line Theorem
Corresponding Angles

Given two parallel lines, we will analyze the effect of cutting them with a transversal (or a line cutting two or more parallel lines.



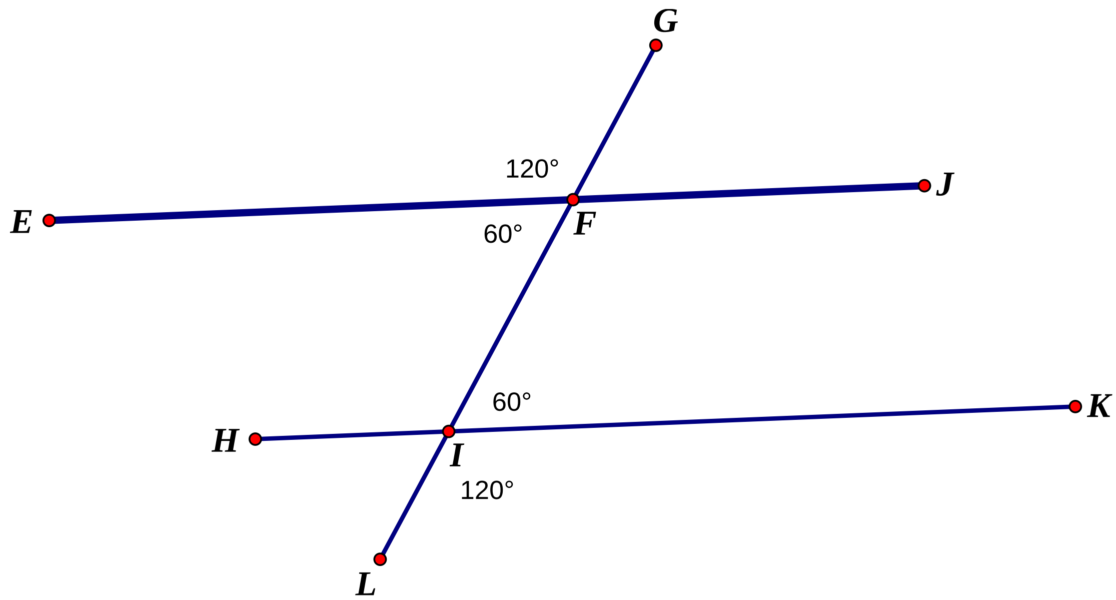
Note that given parallel lines EJ and HK, the angles GFE and FIH are equal. Likewise, angles GFJ and FIK are also equal. These angles are known as corresponding angles. If you were to close the distance between the two parallel lines, you would see that they would **correspond** by superimposing themselves (or being on top of one another). Can you find the other two? We often use an F-pattern to find these angles.



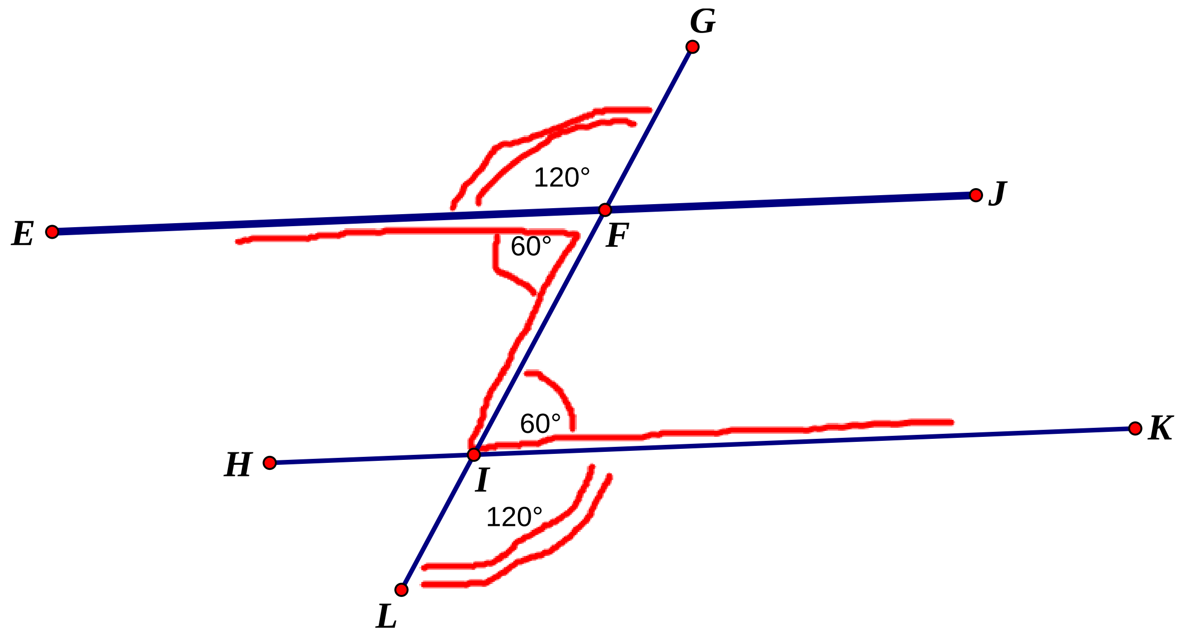
Note that the F is upside down in this case.

The Parallel Line Theorem
Alternating Angles

In this case, if the distance between the two parallel lines we to be eliminated, we would simply have an X and we would be using the Opposite Angle Theorem, hence we have the case of alternating angles. This version of the PLT uses the Z-Pattern.



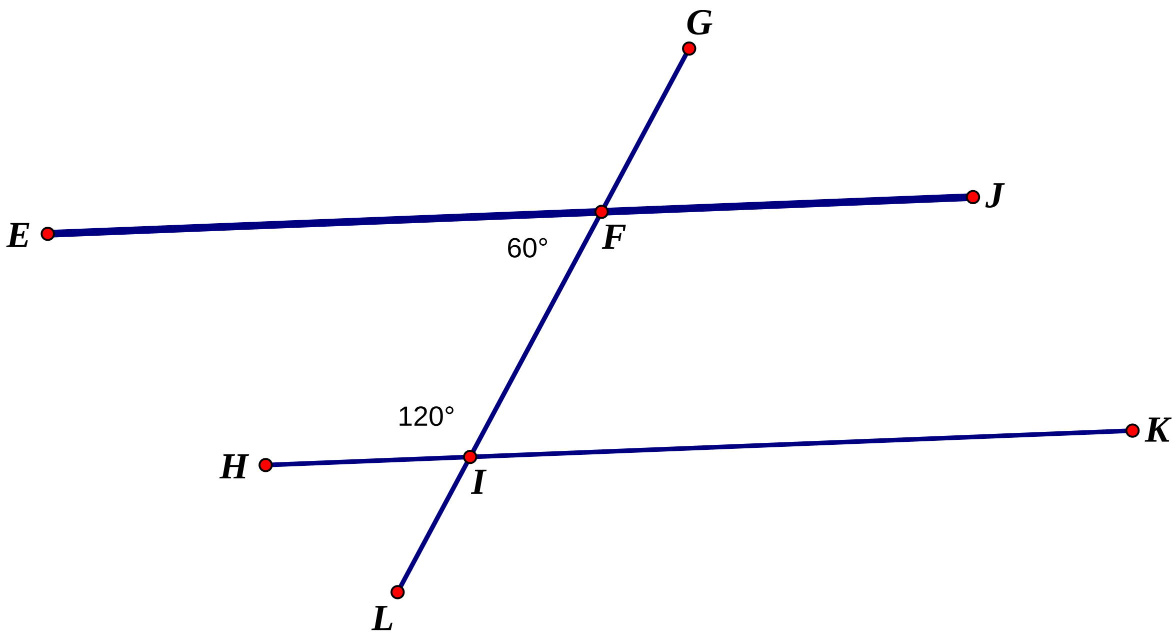
Can you find the other Z – patterns?



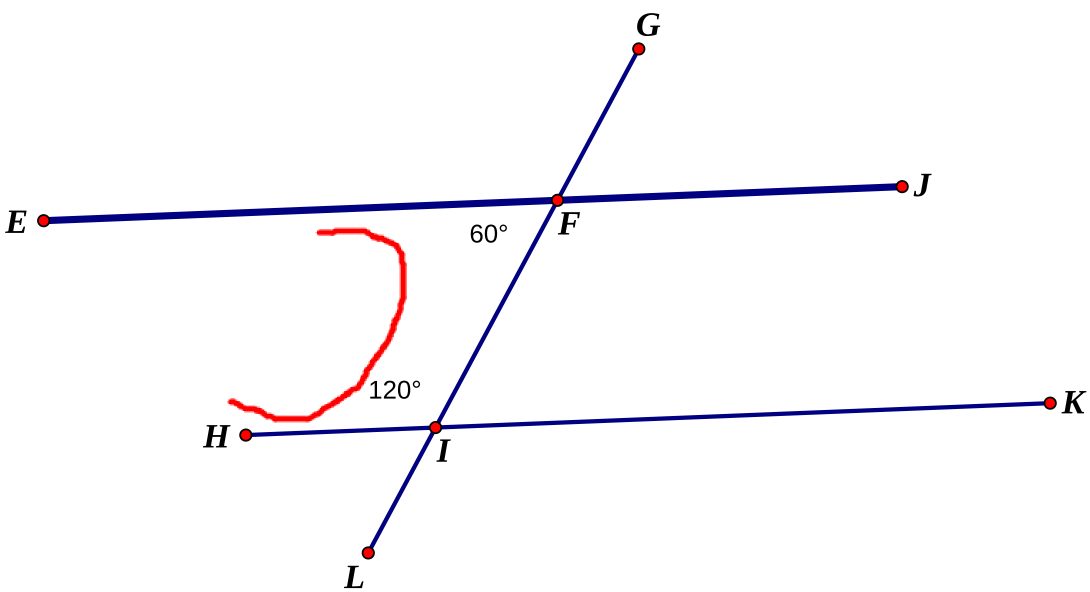
Note that the Z pattern.

The Parallel Line Theorem
Co-Interior Angles

This version of the Parallel Line Theorem utilizes the summation of the two angles between the parallel lines. This version of the PLT uses the C-Pattern.



If the parallel lines did not exist, these two angles would be together on the transversal; hence they would simply be supplementary angles. Ergo, the sum of the two co-interior angles will always be 180°. Can you find the other C – pattern?

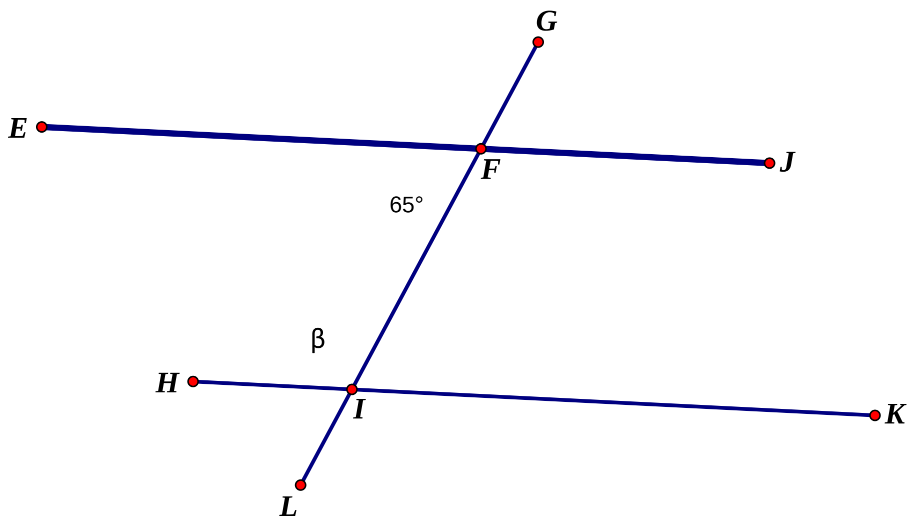


Note that the C – pattern.

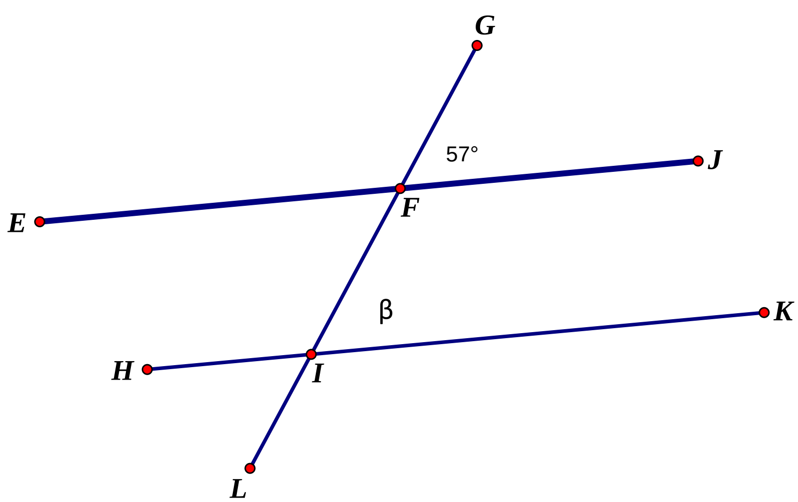
<u>In-class task</u> **Name: ________________**

This task is aimed at acquiring your ability to determine and describe the properties and relationships of the angles formed by parallel lines cut by a transversal, and apply the results to problems involving parallel lines.

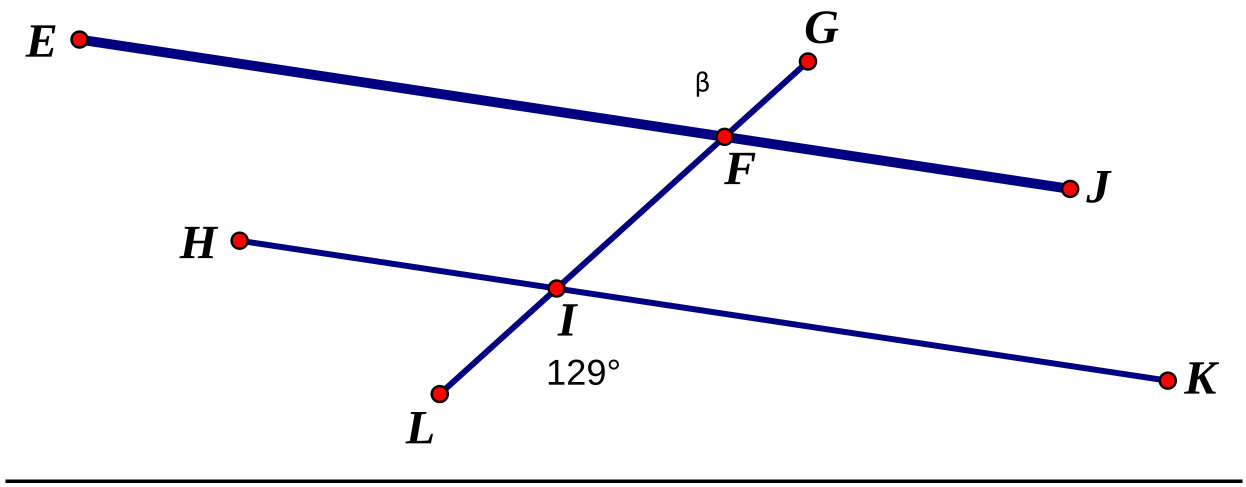
Find the missing angle(s) in each GSP figure below. Justify your answer by stating the theorem which helped you achieve your solution. Be sure to name the angle or pattern that you are using.



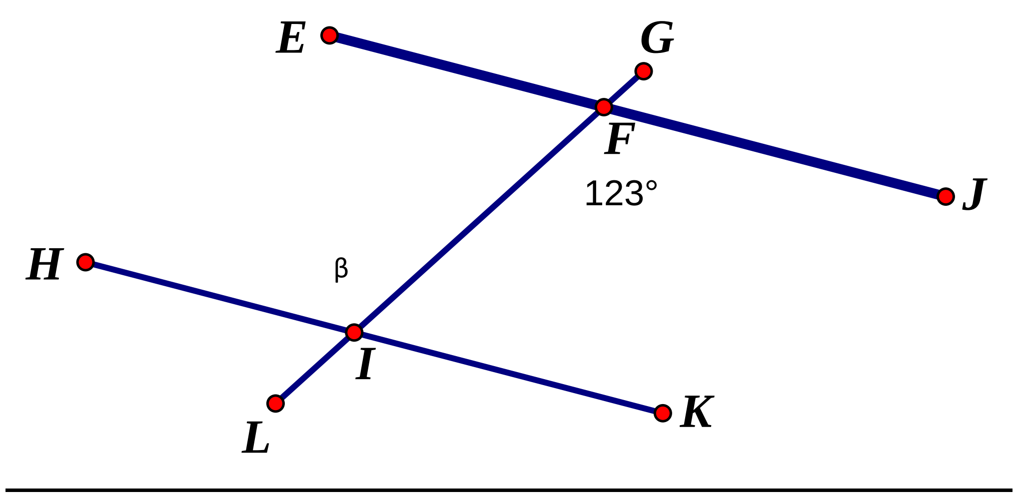
β = ________ **Justification:**



β = ________ **Justification:**



β = ________ **Justification:**



β = ________ **Justification:**

<u>In-class task</u> **Name: __________________**

Create an original dynamic sketch, paperfolding design, or other illustration that incorporates some of the geometric properties from this section, or find and report on some real-life application(s) (e.g., in carpentry, sports, architecture) of the geometric properties.

In this task you will have to design an amusement park which incorporates a laser tag quest.

MOCK EQAO Multiple Choice

Which value of x satisfies the equation:

$$5 - 2x = 9$$

A) $x = -7$ B) $x = -2$ C) $x = 2$ D) $x = 3$

Simplify the following algebraic expression:

$$\frac{a^6 b^4}{a^2 b}$$

A) $\frac{a^3}{b^3}$ B) $\frac{a^4}{b^3}$ C) a^3b^3 D) a^4b^3

If x = 3, what is the value of $2x^2 + 5x$?

A) 21 B) 27 C) 33 D) 51

Suzette expands and simplifies the expression below.

$$2(3x^2 - 5x) + 4x(7 + x)$$

Which expression is equivalent to the one above?

A) $6x^2 + 22x$ B) $10x^2 + 18x$ C) $10x^2 - 38x$ D) $28x^2$

With 12.00$, Samuel and a friend are buying lunch from the menu below.

Menu Tax Included					
Soups & Salads		Sandwiches		Beverages	
Tomato Soup	1.95$	Ham & Cheese	4.65$	Soft Drink	1.35$
Green Salad	2.25$	Turkey	5.15$	Tea/Coffee	0.99$
		Hamburger	3.45$	Juice	1.75$

Which of the following orders could they buy with their 12.00$

A) Two soft drinks and two turkey sandwiches
B) One tomato soup, one tea and two ham & cheese sandwiches
C) One tomato soup, one juice, two green salads and one hamburger
D) One soft drink, one tea, one turkey sandwich and one ham & cheese sandwich

MOCK EQAO Open Response

Alexandre works part-time at a clothing store. He is paid an hourly rate of 10.25$/hr and also earns a commission of 3.5% of his total weekly sales.

Alexandre works at the store 12 hours a week.

If Alexandre's goal is to earn 150$ every week, what do his total weekly sales need to be?

Show your work.

MAJOR UNIT TASK

UNIT REVIEW