MASSACHUSETTS ASSOCIATION OF MATHEMATICS LEAGUES

State Meet - March 27, 2025

Round 1 - Arithmetic and Number Theory

All answers must be in simplest exact form in the answer section.

NO CALCULATORS ALLOWED

1. Compute $53^2 + 53 \cdot 47 + 47^2$.

Solution:

$$= (53+47)^2 - 53 \cdot 47$$
$$= 100^2 - (50+3)(50-3)$$
$$= 100^2 - 50^2 + 3^2$$
$$= \boxed{7509}$$

2. Find the greatest common divisor of 30461 and 56689.

Solution: We denote (a, b) as the GCD of a and b. Using the Euclidean Algorithm, we have

$$(30461, 56689) = (30461, 56689 - 30461)$$
$$= (30461, 26228) = (4233, 26228) = (4233, 830) = (83, 830) = \boxed{83}$$

3. Find the sum of the three 4-digit numbers $\overline{ABCD}$ divisible by 13 such that $2A - 1 = D$ and $B + 1 = C$. Note that $A \neq 0$.

Solution: We have modulo 13 that

$$\overline{ABCD} = 1000A + 100B + 10C + D$$
$$\equiv (1001 - 1)A + (104 - 4)B + (13 - 3)C + D$$

$$\equiv -A - 4B - 3C + D$$

$$= -A - 4B - 3(B+1) + 2A - 1$$

$$= A - 7B - 4$$

$$= A + 6B - 4$$

The possible values (A, B) such that $A + 6B \equiv 4 \pmod{13}$ can be found by plugging in values of B and solving for A. This gives tuples $(4, 0, 1, 7), (11, 1, 2, 21), (5, 2, 3, 9), (12, 3, 4, 23), (6, 4, 5, 11), (0, 5, 6, -1), (7, 6, 7, 13), (1, 7, 8, 1), (8, 8, 9, 15), (2, 9, 10, 3)$. The valid 4-digit numbers are then 4017, 5239, and 1781. Their sum is $\boxed{11037}$.

MASSACHUSETTS ASSOCIATION OF MATHEMATICS LEAGUES

State Meet - March 27, 2025

Round 2 - Algebra I

All answers must be in simplest exact form in the answer section.

NO CALCULATORS ALLOWED

1. Solve for x. Express your answer as a fraction.

$$8^x = 4^{-\frac{3}{2}} \cdot 16^{27^{-\frac{1}{3}}}$$

Solution:

$$\Rightarrow 2^{3x} = 2^{-3}2^{4\cdot\frac{1}{3}}$$

$$\Rightarrow 3x = -3 + \frac{4}{3} = -\frac{5}{3}$$

$$\Rightarrow x = \boxed{-\frac{5}{9}}$$

2. Joey takes x minutes to eat 8 burgers. Emily takes 2 minutes to eat 12 burgers. If Joey and Emily combined take x^2 minutes to eat 350 burgers, solve for x.

Solution: Joey eats $\frac{8}{x}$ burgers a minute. Emily eats $12/2 = 6$ burgers a minute. In x^2 minutes they eat $x^2(\frac{8}{x} + 6) = 8x + 6x^2$ burgers. Then,

$$8x + 6x^2 = 350$$

$$\Rightarrow 3x^2 + 4x - 175 = 0$$

$$\Rightarrow (3x + 25)(x - 7)$$

Since x is positive, we have $x = \boxed{7}$.

3. Let a be the largest real solution to

$$(x^3 + \frac{1}{x^3}) - 3(x^2 + \frac{1}{x^2}) + 5(x + \frac{1}{x}) - 12 = 0$$

Find $a - \frac{1}{a}$.

Solution:

We know $x^2 + \frac{1}{x^2} = (x + \frac{1}{x})^2 - 2$ and $x^3 + \frac{1}{x^3} = (x + \frac{1}{x})^3 - 3(x + \frac{1}{x})$. Then, letting $y = x + \frac{1}{x}$, we have

$$\begin{gathered} y^3 - 3y - 3(y^2 - 2) + 5y - 12 \\ \Rightarrow y^3 - 3y^2 + 2y - 6 \\ \Rightarrow (y - 3)(y^2 + 2) \end{gathered}$$

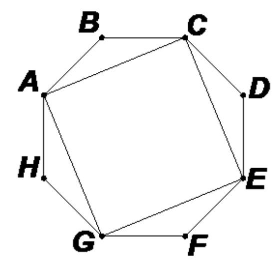
Since x is real, $y = 3$, so $a + \frac{1}{a} = 3$. Then,

$$a - \frac{1}{a} = \sqrt{a^2 - 2 + \frac{1}{a^2}} = \sqrt{(a + \frac{1}{a})^2 - 4} = \boxed{\sqrt{5}}$$

<u>MASSACHUSETTS ASSOCIATION OF MATHEMATICS LEAGUES</u>
State Meet - March 27, 2025
Round 3 - Geometry

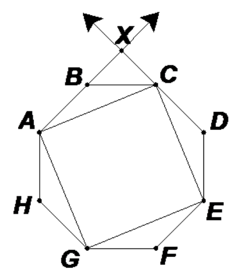
All answers must be in simplest exact form in the answer section.
NO CALCULATORS ALLOWED

1. Regular octagon $ABCDEFGH$ has side length 2. What is the area of the square $ACEG$?

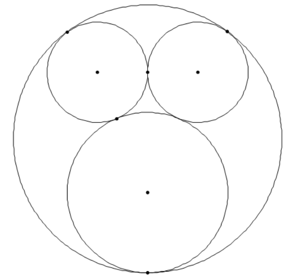


Solution: Extend AB and DC to meet at X. We have ΔXBC is a isosceles right triangle, so $XB = XC = \frac{2}{\sqrt{2}} = \sqrt{2}$. Using the Pythagorean Theorem

$$AC^2 = AX^2 + CX^2 = (2+\sqrt{2})^2 + (\sqrt{2})^2 = \boxed{8+4\sqrt{2}}$$

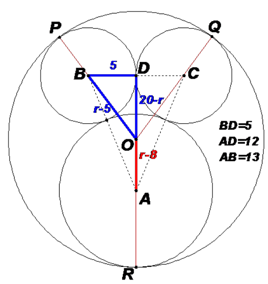


2. Three circles with radii 5, 5, and 8 are all externally tangent to each other. Compute the radius of the circle that circumscribes all three circles. Express your answer as a fraction.

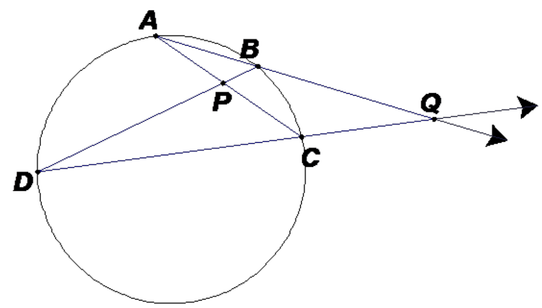


Solution: Let the radius be r. Let the center of the circle with radius 8 be A, and the centers of the circles with radius 5 be B and C. Extend the lines connecting the points of tangency with the circumscribing circle to the centers of the smaller circles, to meet at the center of the circumscribing circle, O. Draw altitude AD of ΔABC. We have $AB = AC = 5 + 8 = 13$ and $BD = CD = 5$, so $AD = 12$ by the Pythagorean Theorem. Also we have $AO = r - 8$ and $BO = r - 5$, so $DO = AD - AO = 20 - r$. By the Pythagorean Theorem on ΔBDO, we have

$$(20 - r)^2 + 5^2 = (r - 5)^2$$
$$\Rightarrow r^2 - 40r + 400 + 25 = r^2 - 10r + 25$$
$$\Rightarrow 30r = 400$$
$$\Rightarrow r = \boxed{\frac{40}{3}}$$



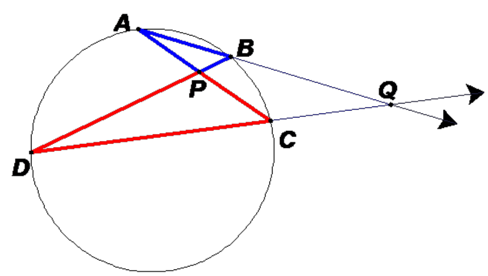
3. Points A, B, C, D lie on a circle. Suppose AC and BD intersect inside the circle at point P, and rays AB and DC intersect outside the circle at point Q. If $AP = 2, DP = 5, BQ = 8, CQ = 6$, find $AB + DC$.



Solution: Let $x = AB$. Since $\Delta ABP \sim \Delta DCP$, we have $AB/DC = AP/DP = \frac{2}{5}$, so $DC = \frac{5}{2}x$. By Power of a Point on Q, we have

$$QB \cdot QA = QC \cdot QD$$
$$\Rightarrow 8(8 + x) = 6(6 + \frac{5}{2}x)$$
$$\Rightarrow 64 + 8x = 36 + 15x$$
$$\Rightarrow 7x = 28$$
$$\Rightarrow AB = 4, DC = 10$$

Thus, $AB + DC = \boxed{14}$.



MASSACHUSETTS ASSOCIATION OF MATHEMATICS LEAGUES

State Meet - March 27, 2025

Round 4 - Algebra II

All answers must be in simplest exact form in the answer section.

NO CALCULATORS ALLOWED

1. Given that x is a positive integer, solve for x.

$$x = 2\log_2(2x)$$

Solution:

$$\Rightarrow 2^x = 2^{2\log_2(2x)}$$

$$\Rightarrow 2^x = (2x)^2 = 4x^2$$

$$\Rightarrow 2^{x-2} = x^2$$

Since x is an integer, x must be a power of 2. Trying small powers of 2, we see that $x = \boxed{8}$.

2. Consider functions $f(x) = ax + 3, g(x) = 2x + b$ where a, b are positive integers. Determine $a + b$, given that $f(g(x)) = g(f(x))$.

Solution: We have $f(g(x)) = a(2x+b)+3 = 2ax+ab+3$ and $g(f(x)) = 2(ax+3)+b = 2ax+b+6$. Thus,

$$ab + 3 = b + 6$$

$$ab - b = 3$$

$$(a-1)b = 3$$

Then, since a, b are positive integers, $a-1$ and b must be 1 and 3, in some order. Then $a-1+b = 1+3 \Rightarrow a+b = \boxed{5}$.

3. Given real x, y such that

$$x\left(1 + \frac{1}{x^2+y^2}\right) = 5$$

$$y(1 - \frac{1}{x^2 + y^2}) = 7$$

compute $z^2 - (5 + 7i)z$ where $z = x + yi$.

Solution: Adding the first equation plus i times the second equation, we get

$$x + yi + \frac{x - yi}{x^2 + y^2} = 5 + 7i$$

Since $x^2 + y^2 = (x - yi)(x + yi)$, we have

$$x + yi + \frac{1}{x + yi} = 5 + 7i$$
$$\Rightarrow z + \frac{1}{z} = 5 + 7i$$
$$\Rightarrow z^2 + 1 = (5 + 7i)z$$
$$\Rightarrow z^2 - (5 + 7i)z = \boxed{-1}$$

MASSACHUSETTS ASSOCIATION OF MATHEMATICS LEAGUES
State Meet - March 27, 2025
Round 5 - Analytic Geometry

All answers must be in simplest exact form in the answer section.
NO CALCULATORS ALLOWED

1. Consider the equation of a circle below. Find the length of a line segment connecting the origin to a point on the circle such that the line segment is tangent to the circle.

$$x^2 - 4x + y^2 + 4y + 7 = 0$$

Solution: Rearranging, we get

$$(x-2)^2 + (y+2)^2 = 1$$

This is a circle centered at $(2, -2)$ with radius 1. The center is $2\sqrt{2}$ away from the origin. By the Pythagorean Theorem, the length of the desired line segment is $\sqrt{(2\sqrt{2})^2 - 1^2} = \boxed{\sqrt{7}}$

2. The graph of the equation below circumscribes a rectangle whose vertical height is double its horizontal width. Find the area of the rectangle. Express your answer as a simplified fraction.

$$4(x-5)^2 + 9(y+2)^2 = 36$$

Solution: The area of the rectangle is the same as that of the rectangle with height double its width and circumscribed by the graph of ellipse

$$4x^2 + 9y^2 = 36$$

The top right corner lies on the line $y = 2x$, so the x-coordinate of this point satisfies

$$4x^2 + 9(2x)^2 = 36$$
$$\Rightarrow 10(2x)^2 = 36$$

$$\Rightarrow 2x = \frac{6}{\sqrt{10}}$$

$$\Rightarrow 2y = \frac{12}{\sqrt{10}}$$

The width and height of the rectangle are $2x$ and $2y$, so the area is

$$\frac{6}{\sqrt{10}}\frac{12}{\sqrt{10}} = \frac{72}{10} = \boxed{\frac{36}{5}}$$

3. Find the area of the region whose vertices are the 4 points at which the graph of the equation below intersects the boundary of the square centered at the origin whose sides are of length 12 and parallel to the axes. Express your answer as a simplified fraction.

$$y = \frac{1}{18}(x^2 - 3x - 108)$$

Solution: The boundary of the square is formed by lines $x = \pm 6, y = \pm 6$. We plug in $x = \pm 6$ to get intersections $(6, -5)$ and $(-6, -3)$. The intersections with $y = 6$ satisfy

$$6 = \frac{1}{18}(x^2 - 3x - 108)$$

$$108 = x^2 - 3x - 108$$

$$x^2 - 3x - 216 = 0$$

which has solutions close to $\sqrt{216}$ which will clearly not be within -6 and 6. Thus, it does not intersect the square on the $y = 6$ line. The intersections with $y = -6$ satisfy

$$-6 = \frac{1}{18}(x^2 - 3x - 108)$$

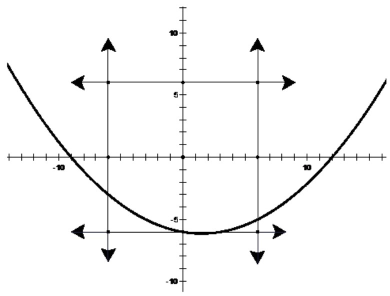
$$-108 = x^2 - 3x - 108$$

$$x(x - 3) = 0$$

so this gives intersections $(0, -6)$ and $(3, -6)$.

We compute the area of the trapezoid with vertices $(-6,-3),(-6,-6),(6,-6),(6,-5)$ minus the areas of the triangles with vertices $(-6,-3),(-6,6),(0,-6)$ and $(6,-6),(6,-5),(3,-6)$, which is $24-9-\frac{3}{2}=\boxed{\frac{27}{2}}$.

Alternatively, you could use the Shoelace Theorem to calculate the area.



MASSACHUSETTS ASSOCIATION OF MATHEMATICS LEAGUES

State Meet - March 27, 2025

Round 6 - Trigonometry and Complex Numbers

All answers must be in simplest exact form in the answer section.

NO CALCULATORS ALLOWED

1. Simplify as much as possible.

$$\frac{\cos(x)\sin(2x)}{\sin(x)-\cos^2(x)+1}-2$$

Solution:

$$=\frac{2\sin(x)\cos^2(x)}{\sin(x)+\sin^2(x)}-2$$

$$=\frac{2\sin(x)(1-\sin^2(x))}{\sin(x)(1+\sin(x))}-2$$

$$=2(1-\sin(x))-2=\boxed{-2\sin(x)}$$

2. Compute the expression below. Express your answer in rectangular form.

$$e^{i\frac{2\pi}{6}}(2+3i)\left(\cos\left(\frac{-5\pi}{6}\right)+i\sin\left(\frac{-5\pi}{6}\right)\right)$$

Solution:

$$=(2+3i)e^{i\frac{2\pi}{6}}e^{-i\frac{5\pi}{6}}$$

$$=(2+3i)e^{-i\frac{\pi}{2}}$$

The $e^{-i\frac{\pi}{2}}$ just rotates $2+3i$ clockwise by $\frac{\pi}{2}$, which gives an answer of $\boxed{3-2i}$

3. Find the number of complex solutions to

$$z^{51}+z^{52}+\cdots+z^{2024}=0$$

Solution:

$$\Rightarrow z^{51}(1 + z + \ldots z^{1973}) = 0$$

$$\Rightarrow z^{51}\frac{z^{1974} - 1}{z - 1}$$

The solutions to this are 0 and the 1974th roots of unity, excluding 1. This gives $\boxed{1974}$ solutions.

MASSACHUSETTS ASSOCIATION OF MATHEMATICS LEAGUES

State Meet - March 27, 2025

Team Round

All answers must be in simplest exact form in the answer section.

NO CALCULATORS ALLOWED

1. How many paths are there from $(0,0)$ to $(5,5)$ such that each move is one of the following 3 options: one step right, one step up, or two steps right and one step up.

Solution: Let $f(x,y)$ be the number of paths from $(0,0)$ to (x,y). Then,

$$f(x,y) = f(x-1,y) + f(x,y-1) + f(x-2,y-1)$$

Starting from $f(0,0) = 1$ and $f(x,y) = 0$ if $x < 0$ or $y < 0$, we can inductively compute $f(x,y)$ for every values $0 \leq x, y \leq 5$, producing this table:

1	6	26	86	241	592
1	5	19	55	136	296
1	4	13	32	68	128
1	3	8	16	28	44
1	2	4	6	8	10
1	1	1	1	1	1

For example, 68 is the sum of the values in the highlighted cells.

Thus, the answer is $\boxed{592}$.

2. Consider the sequence of integers defined as $a_1 = 5$, $a_{n+1} = 3n^2 - 2a_n$. Compute $a_1 + a_2 + \cdots + a_{12}$ given that $a_{13} = 19730$. For reference, the formula for the sum of the first n squares is

$$1^2 + 2^2 + \ldots n^2 = \frac{n(n+1)(2n+1)}{6}$$

Solution: Let $s = \sum_{i=1}^{12} a_i$. Then,

$$s - a_1 + a_{13} = \sum_{i=1}^{12} a_{i+1}$$

$$= \sum_{i=1}^{12} 3i^2 - 2a_i$$

$$= 3\frac{12(12+1)(2 \cdot 12 + 1)}{6} - 2s$$

$$= 1950 - 2s$$

$$\Rightarrow s - 5 + 19730 = 1950 - 2s$$

$$\Rightarrow 3s = -17775$$

$$\Rightarrow s = \boxed{-5925}$$

3. How many integers $n \geq 3$ is it possible that the angles of an n-gon form an arithmetic sequence with a constant difference of $n - 3$ degrees?

Solution: The average of the angles must be $\frac{180(n-2)}{n}$, and the difference between the largest and smallest angle is $(n-1)(n-3)$. Thus, the smallest angle is $\frac{180(n-2)}{n} - \frac{(n-1)(n-3)}{2}$, which we need to be positive. Thus, we want

$$360(n-2) - n(n-1)(n-3) > 0$$

Estimating the polynomial as $360n - n^3$, we get that the maximal value of n should be around 19. We see that

$$360 \cdot 18 - 20 \cdot 19 \cdot 17 = 20(18 \cdot 18 - 19 \cdot 17) > 0$$

and

$$360 \cdot 19 - 21 \cdot 20 \cdot 18 = 20(18 \cdot 19 - 21 \cdot 18) < 0$$

. Thus, the largest possible n is 20, giving us $20 - 3 + 1 = \boxed{18}$ possible values of n.

4. Given distinct positive integers a, b, c that satisfy

$$(a!)(b!)^2(c!)^3 = 2^{14}3^5 5^3$$

compute $a + 2b + 3c$.

Solution: We note that $a, b, c < 7$ since the product has no powers of 7. To get 3 powers of 5, we must have that either $c = 5$ or $c = 6$ or a and b are 5 and 6 in some order.

Case 1 $c = 5$: We have $(5!)^3 = 2^9 3^3 5^3$, so $(a!)(b!)^2 = 2^5 3^2$. Each factorial provides at most one power of 3, so b must be 3 or 4, neither of which give a solution.

Case 2 $c = 6$: We have $(6!)^3 = 2^{12}3^6 5^3$, which is too many powers of 3.

Case 3 $(a, b) = (6, 5)$: We have $(6!)(5!)^2 = 2^{10}3^4 5^3$, so $(c!)^3 = 2^4 3$, which is not possible.

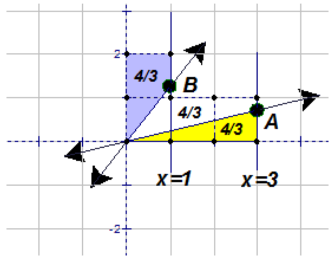
Case 4 $(a, b) = (5, 6)$: We have $(5!)(6!)^2 = 2^{11}3^5 5^3$, so $(c!)^3 = 2^3$, giving solution $(a, b, c) = (5, 6, 2)$. Then, $a + 2b + 3c = \boxed{23}$.

5. On the coordinate place, consider the L-shaped region of area 4 on the plane composed of the unit squares with lower-left corners at $(0, 0)$, $(1, 0)$, $(2, 0)$, and $(0, 1)$. By making cuts along two lines that intersect at the origin, this region is divided into 3 regions of equal area. Compute the sum of the slopes of these two lines. Express your answer as a fraction.

Solution: The cut with smaller slope intersects the region again on line $x = 3$ at a point that forms a triangle with points $(0, 0), (3, 0)$ and an area equal to $4/3$. This point $(3, y)$ then must satisfy $\frac{3y}{2} = \frac{4}{3} \Rightarrow y = \frac{8}{9}$. This gives a slope of $\frac{8}{27}$.

The cut with larger slope intersects the region again on line $x = 1$ at a point that forms a trapezoid with points $(0, 0), (0, 2), (1, 2)$ and an area equal to $4/3$. This point $(1, y)$ then must satisfy $1 \cdot \frac{2+(2-y)}{2} = \frac{4}{3} \Rightarrow y = \frac{4}{3}$. This gives a slope of $\frac{4}{3}$.

Adding these slopes, we get $\boxed{\frac{44}{27}}$.



6. Find the number of values of x between 0 and 10, inclusive, that satisfy

$$\sin(x^2\pi) = \cos(x\pi)$$

Solution: Each time $\sin(x^2\pi)$ goes from -1 to 1 or from 1 to -1, it intersect $\cos(x\pi)$ once. From $x = 0$ to the first time $\sin(x^2\pi) = 1$ at $x = \sqrt{0.5}$, it intersects $\cos(x\pi)$ once since $\cos(x\pi)$ is going from 1 to less than 0. Then, there is one intersection between $\sqrt{0.5} < x < \sqrt{1.5}$, one between $\sqrt{1.5} < x < \sqrt{2.5}$, all the way to an intersection between $\sqrt{98.5} < x < \sqrt{99.5}$. There is no intersection between $\sqrt{99.5} < x < 10$ since $\cos(x\pi)$ is near 1 there while $\sin(x^2\pi)$ is coming up from -1 to 0. Thus, there are $\boxed{100}$ total intersections.

MASSACHUSETTS ASSOCIATION OF MATHEMATICS LEAGUES

State Meet - March 27, 2025

Team Round Answer Sheet

ANSWERS

1. ____________________

2. ____________________

3. ____________________

4. ____________________

5. ____________________

6. ____________________

7. ____________________

8. ____________________

MASSACHUSETTS ASSOCIATION OF MATHEMATICS LEAGUES

State Meet - March 27, 2025

Answer Key

Round 1 - Arithmetic and Number Theory

1. 7509
2. 83
3. 11037

Round 2 - Algebra I

1. $-\frac{5}{9}$
2. 7
3. $\sqrt{5}$

Round 3 - Geometry

1. $8+4\sqrt{2}$
2. $\frac{40}{3}$
3. 14

Round 4 - Algebra II

1. 8
2. 5
3. -1

Round 5 - Analytic Geometry

1. $\sqrt{7}$
2. $\frac{36}{5}$
3. $\frac{27}{2}$

Round 6 - Trigonometry and Complex Numbers

1. $-2\sin(x)$
2. $3-2i$
3. 1974

Team Round

1. 592
2. -5925
3. 18
4. 23
5. $\frac{44}{27}$
6. 100

School: ______________________________

Circle your team below.

Team #1 Team #2 Team #3 Team #4 Team #5

Team #6 Team #7 Team #8 Team #9 Team #10

Name: ______________________________

For Official Use Only
Score:

YES Western Mass ARML Member? NO
(circle one)

Reminders:

- No two students from the same school should be sitting at the same table or in adjacent desks in a classroom.
- All electronic devices should be OFF and not in plain sight.
- Calculators are ***not*** allowed during this round.
- Do not turn this paper over until the moderator says, "Begin!"

MAML State Meet
Round 1: Arithmetic and Number Theory

School: ____

Circle your team below.

Team #1 Team #2 Team #3 Team #4 Team #5

Team #6 Team #7 Team #8 Team #9 Team #10

Name: ____

For Official Use Only
Score:

YES Western Mass ARML Member? NO
(circle one)

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MAML State Meet
Round 2: Algebra I

School: ____

Circle your team below.

Team #1 Team #2 Team #3 Team #4 Team #5

Team #6 Team #7 Team #8 Team #9 Team #10

Name: ____

For Official Use Only
Score:

YES Western Mass ARML Member? NO
(circle one)

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- Do not turn this paper over until the moderator says, "Begin!"

MAML State Meet
Round 3: Geometry

School: ______________________________

Circle your team below.

Team #1	**Team #2**	**Team #3**	**Team #4**	**Team #5**
Team #6	**Team #7**	**Team #8**	**Team #9**	**Team #10**

Name: ______________________________

For Official Use Only

Score:

YES **Western Mass ARML Member?** **NO**
(circle one)

Reminders:

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MAML State Meet
Round 4: Algebra II

School: ____

Circle your team below.

Team #1	**Team #2**	**Team #3**	**Team #4**	**Team #5**
Team #6	**Team #7**	**Team #8**	**Team #9**	**Team #10**

Name: ____

For Official Use Only
Score:

YES **Western Mass ARML Member?** **NO**
(circle one)

Reminders:

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- Do not turn this paper over until the moderator says, "Begin!"

MAML State Meet
Round 5: Analytic Geometry

School: ______________________________

Circle your team below.

Team #1	**Team #2**	**Team #3**	**Team #4**	**Team #5**
Team #6	**Team #7**	**Team #8**	**Team #9**	**Team #10**

Name: ______________________________

For Official Use Only

Score:

YES **Western Mass ARML Member?** **NO**

(circle one)

Reminders:

- No two students from the same school should be sitting at the same table or in adjacent desks in a classroom.
- All electronic devices should be OFF and not in plain sight.
- Calculators are ***not*** allowed during this round.
- Do not turn this paper over until the moderator says, "Begin!"

MAML State Meet
Round 6: Trigonometry and Complex Numbers

MASSACHUSETTS ASSOCIATION OF MATHEMATICS LEAGUES

State Meet - March 27, 2025

TEAM ROUND

School Name: ______________________________

Team #: __________

Team Members:

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Score = __________ / 12