An Introduction to AMM-L

Is AMM-L right for you?

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§1 Welcome

Welcome! If you're reading this document, you're probably aware of OMEGA's newest contest, the **AMM-L** (American Masters of Mathematics Local). In case you've somehow found this document without knowing what AMM-L is, you can find more info about AMM-L here.

However, you might not be sure about what this contest expects of you. This document hopes to clear that up, as well as demonstrate the expected difficulty level of AMM-L.

§2 Format and expectations

§2.1 The contest

The AMM-L is a proof-based contest at roughly the ARML or BAMO-12 level. It will be held in two 90-minute halves. Each half will feature 3 problems, each worth 20 points, and full explanations are expected. Partial credit is available, both explicitly (in multi-part problems) as well as implicitly (for progress towards a full solution). In problems with multiple parts, the point breakdown will be explicitly given.

Despite targeting a similar difficulty as the ARML and other short-answer contests, by asking for full solutions, we emphasize deep thinking over simply getting the correct answer. If you've worked through a difficult problem only to stumble at the end (and get no points) due to an arithmetic mistake, AMM-L might be for you!

§2.2 Grading

Your solutions will be read by expert reviewers. Multiple reviewers will independently read your solutions, and they must agree on a score before that score can be finalized. This ensures that scores are assigned confidently.

§3 Some example problems

Here are some examples of problems that might appear on AMM-L, from a variety of subjects and difficulties.

Important: You should not treat this as a diagnostic exam! While we recommend you try the problems to judge if AMM-L might be the right experience for you, you should not solely make your decision based on how many problems you're able to solve. Instead, you should think

about whether you enjoy the feeling of tackling these kinds of problems. If so, then AMM-L might be right for you, even if the problems might feel difficult!

1. **[20]** Find the number of permutations $a_1, \ldots, a_7$ of $1, \ldots, 7$ satisfying
$$\max(a_1, a_2) \le \max(a_2, a_3) \le \cdots \le \max(a_6, a_7).$$

2. **[20]** Given that a, b, c are real numbers satisfying
$$a^2 + ab + b^2 = b^2 + bc + c^2 = c^2 + ca + a^2 = 3,$$
find all possible values of $a + b + c$.

3. An ordered triple of positive real numbers (a, b, c) is a *paragon* if exist angles α, β, γ such that
$$a\sin(\theta + \alpha) + b\sin(\theta + \beta) + c\sin(\theta + \gamma) = 0$$
for all angles θ.
   (a) **[8]** Prove that $(7, 17, 27)$ is not a paragon.
   (b) **[12]** Find all paragons.

4. **[20]** Hexagon $ABCDEF$ is inscribed in circle Ω with center O. Diagonals $\overline{AD}$, $\overline{BE}$, $\overline{CF}$ intersect at P. Suppose that $\angle APB = \angle CPD = \angle EPF$, $AD + BE + CF = 38$, the area of $ABCDEF$ is $85\sqrt{3}$, and $OP = \sqrt{74}$. Find the radius of Ω.

§4 How do I write proofs?

Contrary to what you might expect, a proof is simply an explanation: a "rigorous" proof is just a synonym for a correct explanation. If you're wondering how to explain your solution, that's all you need to do: simply explain your solution so that someone else can understand it.

§4.1 Things to know

The following describes the basics of proofwriting and grading.

- If you explain your solution, your logic is correct, and graders are able to understand your solution, you'll get full points.
- If you have an incomplete solution, where the graders recognize you've made partial progress according to the rubric, you'll get points accordingly.
- If you thought you had a full solution, but don't receive full points, then either your solution wasn't correct, or your solution was written so poorly that multiple graders could not understand your work.

§4.2 Important: observing a pattern isn't a proof

Experimenting with a problem and observing a pattern is a perfectly fine way to approach a problem. However, a pattern is not a proof.

One of the most famous examples of this phenomenon is the following:

Example 4.1

Let n be a nonnegative integer. Suppose n points are chosen on a circle, and all $\binom{n}{2}$ chords between them are drawn. Given that no three of these chords intersect at a single point, find the number of regions the circle is divided into.

If you try to approach this problem by trying small cases, you'll find that the answers for $n = 0$, 1, 2, 3, 4 are 1, 2, 4, 8, 16.

Thus, you might guess that the answer for n points is 2^n regions. However, this is not correct: the answer for 5 points is 31 regions. In general, it turns out that for n points, there are exactly $\binom{n}{0} + \binom{n}{1} + \binom{n}{2} + \binom{n}{3} + \binom{n}{4}$ regions.

That said, even if a pattern turns out to be correct, it still must be proved.

§5 What if AMM-L isn't for me?

You might be reading through this document and thinking that AMM-L might be too daunting for you. Perhaps the example problems seem too unapproachable, or you simply might not like the contest environment.

- If you prefer to try problems without time pressure, the problems will be released shortly after the contest concludes, so you can try the problems at your own pace.
- If you think the problems feel too intimidating, OMEGA hopes to offer more accessible events in the future. . .stay tuned!

§A Appendix: Examples of solution-writing

This section contains several writeups for the same problem, along with how they might be graded. If you're interested in the specifics of grading, you may find this interesting.

Here is a problem that could appear on AMM-L, taken from the list of example problems.

Example

Given that a, b, c are real numbers satisfying

$$a^2 + ab + b^2 = b^2 + bc + c^2 = c^2 + ca + a^2 = 3,$$

find all possible values of $a + b + c$.

This is an example of a problem with an answer: the set of possible values of $a + b + c$. This is also implicitly a two-part problem: we need to show that all of our claimed possibilities for $a + b + c$ are valid, and that we didn't miss any possibilities.

§A.1 Solution 1: only answer

> -3, 0, 3

This solution only contains an answer to the problem. Even though the answer is correct, this solution would likely get a low score, or perhaps even no credit if graders expect that the answer is easy to guess.

§A.2 Solution 2: incorrect answer with little work

> $a = b = c = -1$ works, and $a+b+c = -3$. $a = b = c = 1$ also works, and $a+b+c = 3$.
>
> No other possibilities work. So, the answer is -3 and 3.

This solution includes some work, showing that -3 and 3 are possible values of $a+b+c$. However, it has two issues:

- The possibility $a + b + c = 0$ is ignored: the solution simply claims that it's not possible.
- Like the previous solution, this solution also doesn't show that there aren't any other possible values of $a + b + c$.

Because of these issues, this solution would likely also get a low score.

§A.3 Solution 3: genuine progress, with math and logic slip-ups

> We know that $a^2 + ab + b^2 = 3$. Multiply both sides by $a - b$, so $a^3 - b^3 = 3(a - b)$, or $a^3 - 3a = b^3 - 3b$. Repeating this logic, we see that $a^3 - 3a = b^3 - 3b = c^3 - 3c$. Let this common value equal p. Then a, b, c are the three solutions to the equation $x^3 - 3x - p = 0$. By Vieta's formulas, we see that $a + b + c = 0$, so the answer is 0.

Unlike the first two solutions, this solution starts with the given equations, and makes progress from there. However, it still has some issues:

- The solution shows that $a + b + c$ must be 0. However, this is a two-part problem: we still need to show that 0 is a possible value of $a + b + c$.

- Despite the progress, there is a mathematical error: the solution claims that a, b, c are "the three" solutions to the cubic. This is only valid if a, b, c are all different. If some of them are the same, then this doesn't account for all the solutions, and so the cubic may have extra solutions.

Despite the mistake at the end, this attempt contains genuine progress towards a full solution. It would likely receive some partial credit, though how much partial credit it receives would depend on the rubric for this problem.

§A.4 Solution 4: full solution, poorly presented, mathematical typo

> -3, 0, 3. For 3 take all 1s and for -3 take all -1s. For 0 take 1, 1, -2, so these all work. Since $a^2+ab+b^2 = 3$, $a^3-b^3 = (a-b)(a^2+ab+b^2) = 3(a-b)$, and $a^3-3a = b^3-3b$. c^3-3c is also equal to this, say p. So a, b, c are all roots of $x^3-3x-p = 0$. If $a \neq b \neq c$, then Vieta's formulas say that $a+b+c = 0$. If not, WLOG $a = b$. Then $3a^2 = 3$, so $a = 1$ or -1. If $a = 1$, then $a^2+ac+c^2 = 3 = a^2+a+1$, so $a^2+a-2 = 0$. Thus $a = 1$ or -2, so $a+b+c = 3$ or 0. Similarly, if $a = -1$, then $a+b+c = -3$ or 0.

This is (almost) a full solution, but very difficult to read: equations are interspersed with the text, making them hard to see. However, it also has a small mathematical typo: it writes $a \neq b \neq c$ when it means "a, b, c are all different." However, it does not include $c \neq a$.

Despite being a mathematical error, it is clear what the solution meant. Thus, this particular mistake would likely not warrant deducting any points.

Overall, despite the difficulty of reading the solution, this solution would likely get full points. However, this style of solution can get extremely difficult to read, especially if the solution is long, and such solutions are susceptible to misinterpretation.

The next solution shows a version of this solution that is longer, but easier to read.

§A.5 Solution 5: full solution, nicely presented

> The answers are -3, 0, 3.
>
> We show that they are all possible:
>
> - If $a = b = c = -1$, then the equations are satisfied, and $a+b+c = -3$.
> - If $a = \sqrt{3}$, $b = -\sqrt{3}$, and $c = 0$, then the equations are satisfied, and $a+b+c = 0$.
> - If $a = b = c = 1$, then the equations are satisfied, and $a+b+c = 3$.
>
> Now, suppose that the equations are satisfied. Then
>
> $$\begin{aligned} & a^2+ab+b^2 = 3 \\ \implies & (a^2+ab+b^2)(a-b) = 3(a-b) \\ \iff & a^3-b^3 = 3a-3b \\ \iff & a^3-3a = b^3-3b. \end{aligned}$$
>
> Similarly, we have
>
> $$a^3-3a = b^3-3b = c^3-3c.$$
>
> Let p denote this common value.
>
> If a, b, c are all different, then they are the three solutions of $x^3-3x-p = 0$. Thus, by Vieta's formulas, we obtain $a+b+c = 0$.
>
> If a, b, c are not all different, then without loss of generality suppose $a = b$. Then
>
> $$a^2+ab+b^2 = 3 \implies 3a^2 = 3 \implies a = b = \pm 1.$$

Suppose that $a = b = 1$. Then, we see that

$$a^2 + ac + c^2 = 3 \implies c^2 + c - 2 = 0,$$

so $c = 1$ or $c = -2$, and $a + b + c$ is either 3 or 0.

Similarly, if $a = b = -1$, then $a + b + c$ is either -3 or 0. Thus, the possible values of $a + b + c$ are -3, 0, and 3.

This solution is both fully correct and nicely formatted:

- The logic is fully correct. While the solution simply claims "the equations are satisfied" three times, these claims are easy to check: simply plug in the numbers, and show that the equations work.
- The solution solves both parts of the problem:
  1. It shows that -3, 0, and 3 are all possible values of $a + b + c$.
  2. It shows that every possible value of $a + b + c$ is either -3, 0, or 3; i.e., no other values are possible.
- This solution emphasizes complicated equation chains, making them easier to read. A reader can easily see the main equations involved in the solution.

While solutions are graded on correctness, if a correct solution is so poorly written that graders can't understand it, the solution will get a low score. Thus, while it's not an explicit component of grading, you should still aim to write your solutions cleanly.