

MAST Diagnostic

Math Advance!

Season 3

1 Rules and Instructions

The MAST Diagnostic is a selection of problems the staff team has written that have appeared in various contests. Because the first lecture is so soon, I've abridged the diagnostic to 8 computational problems and 0 proof. (You're welcome.)

Major changes:

- The proof section is entirely removed; computational has been fixed to be 8 problems total, 2 per each subject. One problem is easy-medium and the other is medium-hard in difficulty. **However, there are still some things you must prove:** I will make it clear if I want a full and rigorous proof for a "find-all" style problem.¹ **Solution sketches, at a minimum, are still mandatory.** Convince me you know how to solve the problem on your own.²
- The points system has been removed.³ Part of the reason is because the relative difficulty of each problem should be clear, given there's only two per subject.
- You must indicate if you remember a past problem.
- If you think you've accidentally broken any of these rules, please let me know. The difference between cheating and a mistake is **transparency**.
- If you've deliberately broken any of these rules, please also let me know. I believe that cheaters can become better people. Please prove me right.

1.1 Asking for Help

If you've been stuck on a problem for a while and want a hint, you can ask me **or other people**. You may also consult static media. (This includes books, articles, and parts of the internet such as encyclopedias or other references. This **does not** include making a forum post on AoPS or StackExchange. You also may not look for the problem.) If you do ask other people, here are a couple of rules:

- Do not ask any MAST students/applicants/potential applicants.
- The person helping you should know that they are helping you on a diagnostic intended to gauge your ability. So they should not give you the entire solution and instead be giving helpful hints.

¹Nevertheless, problems will still mostly be computational in nature.

²This used to be a saying I stole to indicate how much work you needed to do, but based on the number of cheaters last season, I actually mean it when I say it this time.

³It only ended up discouraging the people who had less of a chance to make it, which is the last thing I want to do. And people kept asking me "how much should I do" anyway, so it didn't save me any questions. (For the record, please don't ask how much you need to do: the answer is "as much as you can, to a reasonable extent.")

- Don't try to get the solution, try to get small hints. Just enough to get you moving forward on the problem.
- You **must** indicate to me that you have asked someone for help, and you must indicate to me how they have helped you. (Even if it wasn't actually helpful in the end.)

I want to stress that these are not suggestions or requests. These are hard rules that **must be followed** if you ask someone else for help. **Deliberately omitting any of these steps is academic dishonesty, and may get you banned from the program.** Some examples of people you can ask: past/current students, your math coach, your parents, college friends, people overqualified to be a student of the program,⁴ et cetera.

1.2 Seen Before

Because these are mostly problems that've appeared elsewhere, some applicants may have seen some of the problems. Policy change from last year: **if there is any way you may have been exposed to the problem before**, such as taking JMC and/or reviewing the solutions packet, **indicate this in your PDF submission.**⁵

Something that might be obvious but should be explicitly stated anyway: if you intend to apply, you should not look at any of the problems after you've seen this document. Nor should you frantically review JMC/NARML to "prepare" for this application. You know what's right and what's not, so please don't make yourself look stupid by claiming that something obviously unfair is "technically not cheating."

⁴If this describes you and you want to get involved with the program, shoot me a PM! I always appreciate more staff.

⁵Contrary to what might be popular belief, you actually have better chances if you have done MAC contests. Those of you who have followed my streams more closely know that **I am a nepotist**, and I think that if you care enough to take our mock contests, you deserve to make the program. Obviously I won't really factor it in either way, since your problemset, essays, and contest scores (to a lesser extent) are much more important to me.

2 Problems

2.1 Algebra

A1. What is the value of

$$\frac{(2019 + 2020)(2020 + 2021)(2021 + 2019) + 2019 \cdot 2020 \cdot 2021}{2019 \cdot 2020 + 2020 \cdot 2021 + 2021 \cdot 2019}?$$

A2. Find $\sum_{a=1}^{\infty} \frac{32a}{16a^4 + 24a^2 + 25}$.

2.2 Combo

C1. Steven has 4 lit candles and each candle is blown out with a probability $\frac{1}{2}$. After he finishes blowing, he randomly selects a possibly empty subset out of all the candles. What is the probability his subset has at least one lit candle?

C2. For each positive integer n , let $s(n)$ denote the sum of the digits of n when written in base 10. An integer x is said to be **tasty** if

$$s(11x) = s(101x) = s(1001x) = \cdots = 18.$$

How many **tasty** integers are less than 10^8 ?

2.3 Geometry

G1. Consider parallelogram $ABCD$ with $AB = 7$, $BC = 6$. Let the angle bisector of $\angle DAB$ intersect BC at X and CD at Y . Let the line through X parallel to BD intersect AD at Q . If $QY = 6$, find $\cos \angle DAB$.

G2. An equilateral triangle ACK is located inside a regular decagon $ABCDEFGHIJ$. If the area of the decagon is 1, find the area of $HIJAK$.

2.4 Number Theory

N1. Compute the smallest positive integer n such that $9(n + 3)$ divides $4n! + n + 5$.

N2. Find all positive integers n such that

$$\frac{1! \cdot 2! \cdot 3! \cdots 2019! \cdot 2020!}{n!}$$

is a perfect square.