2018 AMC 12A Solutions

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1. A large urn contains 100 balls, of which 36% are red and the rest are blue. How many of the blue balls must be removed so that the percentage of red balls in the urn will be 72%? (No red balls are to be removed.)

   A 28

   B 32

   C 36

   D 50

   E 64

   ### Solution:

   There are 36 red balls, and this count stays fixed. For the red balls to be 72% of the urn, the urn must contain $36 \div 0.72 = 50$ balls. Since $100 - 50 = 50$, exactly 50 blue balls are removed.

   Thus, the correct answer is **D**.

2. While exploring a cave, Carl comes across a collection of 5-pound rocks worth $\$14$ each, 4-pound rocks worth $\$11$ each, and 1-pound rocks worth $\$2$ each. There are at least 20 of each size. He can carry at most 18 pounds. What is the maximum value, in dollars, of the rocks he can carry out of the cave?

- A 48
- B 49
- C 50
- D 51
- E 52

Solution:

The rocks are worth $\$2.80$, $\$2.75$, and $\$2$ per pound respectively, so the 1-pound rocks are never worthwhile. Testing how many 5-pound rocks to take and filling the rest with 4-pound rocks: three 5-pound rocks plus three 1-pound rocks give $\$42 + \$6 = \$48$; two 5-pound and two 4-pound rocks use all 18 pounds for $\$28 + \$22 = \$50$; one 5-pound, three 4-pound, and one 1-pound rock give $\$49$.

The maximum value is $\$50$. Thus, the correct answer is **C**.

3. How many ways can a student schedule 3 mathematics courses—algebra, geometry, and number theory—in a 6-period day if no two mathematics courses can be taken in consecutive periods? (What courses the student takes during the other 3 periods is of no concern here.)

A 3

B 6

C 12

D 18

E 24

Solution:

The choices of three non-consecutive periods are $\{1,3,5\}$, $\{1,3,6\}$, $\{1,4,6\}$, and $\{2,4,6\}$, a total of 4. The three distinct courses can be placed into any such set in $3! = 6$ orders, giving $4 \cdot 6 = 24$ schedules.

Thus, the correct answer is **E**.

4. Alice, Bob, and Charlie were on a hike and were wondering how far away the nearest town was. When Alice said, "We are at least 6 miles away," Bob replied, "We are at most 5 miles away." Charlie then remarked, "Actually the nearest town is at most 4 miles away." It turned out that none of the three statements was true. Let d be the distance in miles to the nearest town. Which of the following intervals is the set of all possible values of d?

A $(0, 4)$

B $(4, 5)$

C $(4, 6)$

D $(5, 6)$

E $(5, \infty)$

Solution:

Negating the three false statements gives $d < 6, d > 5,$ and $d > 4.$ The intersection of these conditions is $5 < d < 6,$ that is, the interval $(5, 6).$

Thus, the correct answer is **D**.

5. What is the sum of all possible values of k for which the polynomials $x^2 - 3x + 2$ and $x^2 - 5x + k$ have a root in common?

- A 3
- B 4
- C 5
- D 6
- E 10

Solution:

Since $x^2 - 3x + 2 = (x-1)(x-2)$, its roots are 1 and $2.$ If 1 is a shared root then $1 - 5 + k = 0$, so $k = 4.$ If 2 is a shared root then $4 - 10 + k = 0$, so $k = 6.$ The sum of possible values is $4 + 6 = 10.$

Thus, the correct answer is **E**.

6. For positive integers m and n such that $m+10<n+1$, both the mean and the median of the set $\{m, m+4, m+10, n+1, n+2, 2n\}$ are equal to n. What is $m+n$?

A 20

B 21

C 22

D 23

E 24

Solution:

Because $m+10<n+1$, the six numbers are already increasing, so the median is the average of the middle two: $\frac{(m+10)+(n+1)}{2}=n$, giving $m=n-11$. The mean condition is

$$\frac{(n-11)+(n-7)+(n-1)+(n+1)+(n+2)+2n}{6}=n,$$

so $7n-16=6n$ and $n=16$. Then $m=5$, and $m+n=21$.

Thus, the correct answer is **B**.

7. For how many (not necessarily positive) integer values of n is the value of

$$4000 \cdot \left(\frac{2}{5}\right)^n$$

an integer?

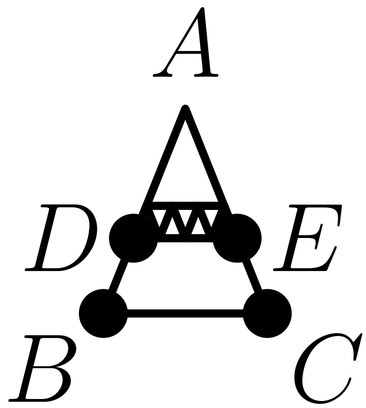
- A 3
- B 4
- C 6
- D 8
- E 9

Solution:

Since $4000 = 2^5 \cdot 5^3$, the expression equals $2^{5+n} \cdot 5^{3-n}$. This is an integer exactly when both $5 + n \geq 0$ and $3 - n \geq 0$, that is, $-5 \leq n \leq 3$. There are $3 - (-5) + 1 = 9$ such integers.

Thus, the correct answer is **E**.

8. All of the triangles in the diagram below are similar to isosceles triangle ABC, in which $AB = AC$. Each of the 7 smallest triangles has area 1, and $\triangle ABC$ has area 40. What is the area of trapezoid $DBCE$?



A 16

B 18

C 20

D 22

E 24

Solution:

The base DE of $\triangle ADE$ is 4 times the base of a smallest triangle, so by the square scaling of similar areas, $[ADE] = 4^2 \cdot 1 = 16$. The trapezoid $DBCE$ is what remains of $\triangle ABC$, so its area is $40 - 16 = 24$.

Thus, the correct answer is **E**.

9. Which of the following describes the largest subset of values of y within the closed interval $[0, \pi]$ for which

$$\sin(x+y) \leq \sin(x) + \sin(y)$$

for every x between 0 and π, inclusive?

- A $y = 0$
- B $0 \leq y \leq \frac{\pi}{4}$
- C $0 \leq y \leq \frac{\pi}{2}$
- D $0 \leq y \leq \frac{3\pi}{4}$
- E $0 \leq y \leq \pi$

Solution:

For $0 \leq x \leq \pi$ and $0 \leq y \leq \pi$ we have $\sin x \geq 0, \sin y \geq 0, \cos x \leq 1,$ and $\cos y \leq 1.$ Hence

$$\sin(x+y) = \sin x \cos y + \cos x \sin y \leq \sin x + \sin y.$$

The inequality therefore holds for every y with $0 \leq y \leq \pi.$

Thus, the correct answer is **E**.

10. How many ordered pairs of real numbers (x, y) satisfy the following system of equations?

$$x + 3y = 3$$

$$\big||x| - |y|\big| = 1$$

- A 1
- B 2
- C 3
- D 4
- E 8

Solution:

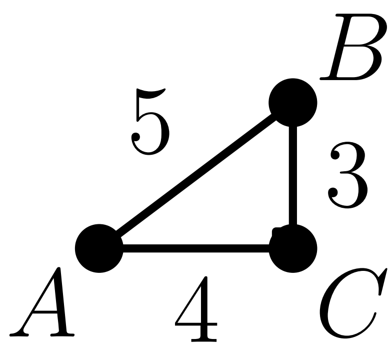
The second equation gives $|x| - |y| = \pm 1$, equivalently $x = \pm y \pm 1$. Substituting into $x + 3y = 3$:

If $x = y + 1$, then $(x, y) = \left(\frac{3}{2}, \frac{1}{2}\right)$. If $x = y - 1$, then $(x, y) = (0, 1)$. If $x = -y + 1$, then again $(x, y) = (0, 1)$. If $x = -y - 1$, then $(x, y) = (-3, 2)$.

The distinct solutions are $(-3, 2)$, $(0, 1)$, and $\left(\frac{3}{2}, \frac{1}{2}\right)$, all of which check, so there are $3.$

Thus, the correct answer is **C**.

11. A paper triangle with sides of lengths $3, 4,$ and 5 inches, as shown, is folded so that point A falls on point B. What is the length in inches of the crease?



A $1+\frac{1}{2}\sqrt{2}$

B $\sqrt{3}$

C $\frac{7}{4}$

D $\frac{15}{8}$

E 2

Solution:

The crease lies along the perpendicular bisector of AB, meeting AC at E because $AC > BC$. Let D be the midpoint of AB, so $AD = \frac{5}{2}$ and $\triangle ADE$ is right-angled at D. Since $\triangle ADE \sim \triangle ACB$, we have $\frac{DE}{AD} = \frac{CB}{AC} = \frac{3}{4}$, so

$$DE = \frac{5}{2} \cdot \frac{3}{4} = \frac{15}{8}.$$

Thus, the correct answer is **D**.

12. Let S be a set of 6 integers taken from $\{1, 2, \ldots, 12\}$ with the property that if a and b are elements of S with $a < b$, then b is not a multiple of a. What is the least possible value of an element of S?

A 2

B 3

C 4

D 5

E 7

Solution:

Partition $\{1, \ldots, 12\}$ into the six divisibility chains $\{1, 2, 4, 8\}, \{3, 6, 12\}, \{5, 10\}, \{7\}, \{9\}, \{11\}$. Since no element of S may divide another, at most one comes from each chain; needing 6 elements forces exactly one from each, so $7, 9, 11 \in S$.

Because $9 \in S, 3 \notin S$, so the second chain contributes 6 or 12, and then neither 1 nor 2 can be chosen from the first chain (they divide 6 and 12). Taking 4 from the first chain works: $S = \{4, 5, 6, 7, 9, 11\}$ has the property. Hence the least possible element is 4.

Thus, the correct answer is **C**.

13. How many nonnegative integers can be written in the form

$$a_7 \cdot 3^7 + a_6 \cdot 3^6 + a_5 \cdot 3^5 + a_4 \cdot 3^4 + a_3 \cdot 3^3 + a_2 \cdot 3^2 + a_1 \cdot 3^1 + a_0 \cdot 3^0,$$

where $a_i \in \{-1, 0, 1\}$ for $0 \le i \le 7$?

A 512

B 729

C 1094

D 3281

E $59{,}048$

Solution:

Adding 1 to every a_i gives a bijection between these expressions and the base-3 numerals for 0 through $3^8 - 1$, so exactly $3^8 = 6561$ distinct integers occur. They are symmetric about 0 (negating all a_i negates the value), so besides 0 itself, half are positive:

$$1 + \tfrac{1}{2}(6561 - 1) = 3281$$

nonnegative integers, namely 0 through 3280.

Thus, the correct answer is **D**.

14. The solution to the equation $\log_{3x} 4 = \log_{2x} 8$, where x is a positive real number other than $\frac{1}{3}$ or $\frac{1}{2}$, can be written as $\frac{p}{q}$, where p and q are relatively prime positive integers. What is $p + q$?

A 5

B 13

C 17

D 31

E 35

Solution:

Writing both logarithms in base $2: \frac{2}{\log_2 3x} = \frac{3}{\log_2 2x}$, so $2\log_2 2x = 3\log_2 3x$, i.e. $(2x)^2 = (3x)^3$. Then $4x^2 = 27x^3$, giving $x = \frac{4}{27}$. Since $\gcd(4, 27) = 1$, we get $p + q = 4 + 27 = 31$.

Thus, the correct answer is **D**.

15. A scanning code consists of a 7×7 grid of squares, with some of its squares colored black and the rest colored white. There must be at least one square of each color in this grid of 49 squares. A scanning code is called *symmetric* if its look does not change when the entire square is rotated by a multiple of 90° counterclockwise around its center, nor when it is reflected across a line joining opposite corners or a line joining midpoints of opposite sides. What is the total number of possible symmetric scanning codes?

- A 510
- B 1022
- C 8190
- D 8192
- E $65{,}534$

Solution:

Under the symmetry group of the square, the 49 cells break into orbits, and every cell in an orbit must have the same color. Classifying cells by distance from the center yields exactly 10 orbits that can be colored independently. Each orbit is black or white, giving 2^{10} colorings, but the all-black and all-white grids are excluded. So there are $2^{10} - 2 = 1022$ symmetric scanning codes.

Thus, the correct answer is **B**.

16. Which of the following describes the set of values of a for which the curves $x^2 + y^2 = a^2$ and $y = x^2 - a$ in the real xy-plane intersect at exactly 3 points?

A $a = \frac{1}{4}$

B $\frac{1}{4} < a < \frac{1}{2}$

C $a > \frac{1}{4}$

D $a = \frac{1}{2}$

E $a > \frac{1}{2}$

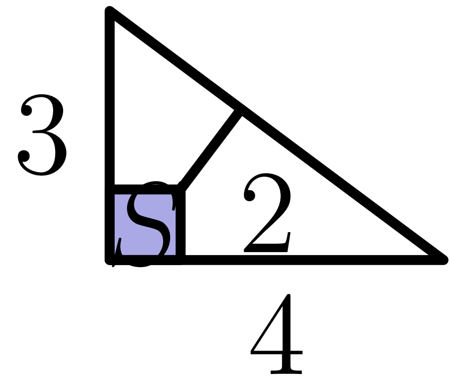
Solution:

Substituting $x^2 = y + a$ into $x^2 + y^2 = a^2$ gives $y^2 + y + (a - a^2) = 0$, which factors as $(y + 1 - a)(y + a) = 0$, so $y = a - 1$ or $y = -a$. These correspond to $x^2 = 2a - 1$ and $x^2 = 0$.

The equation $x^2 = 0$ always gives the single point $(0, -a)$, the vertex of the parabola. The equation $x^2 = 2a - 1$ gives two more points exactly when $2a - 1 > 0$, i.e. $a > \frac{1}{2}$. So there are 3 intersection points precisely when $a > \frac{1}{2}$.

Thus, the correct answer is **E**.

17. Farmer Pythagoras has a field in the shape of a right triangle. The right triangle's legs have lengths of 3 and 4 units. In the corner where those sides meet at a right angle, he leaves a small unplanted square S so that from the air it looks like the right angle symbol. The rest of the field is planted. The shortest distance from S to the hypotenuse is 2 units. What fraction of the field is planted?



A $\frac{25}{27}$

B $\frac{26}{27}$

C $\frac{73}{75}$

D $\frac{145}{147}$

E $\frac{74}{75}$

Solution:

Place the right angle at the origin with legs on the axes, so the vertices are $(4,0)$, $(0,3)$, $(0,0)$, and the square S is $[0,s]\times[0,s]$. The hypotenuse is $3x+4y-12=0$, and the distance from its nearest corner (s,s) is

$$\frac{|3s+4s-12|}{\sqrt{3^2+4^2}}=\frac{|7s-12|}{5}=2.$$

This gives $s=\frac{22}{7}$ or $s=\frac{2}{7}$; only $s=\frac{2}{7}$ keeps the square inside the triangle.

The field has area $\frac{1}{2}\cdot 3\cdot 4=6$ and the unplanted square has area $\left(\frac{2}{7}\right)^2=\frac{4}{49}$. The planted fraction is

$$1 - \frac{4/49}{6} = 1 - \frac{2}{147} = \frac{145}{147}.$$

Thus, the correct answer is **D**.

18. Triangle ABC with $AB = 50$ and $AC = 10$ has area 120. Let D be the midpoint of $\overline{AB}$, and let E be the midpoint of $\overline{AC}$. The angle bisector of $\angle BAC$ intersects $\overline{DE}$ and $\overline{BC}$ at F and G, respectively. What is the area of quadrilateral $FDBG$?

- A 60
- B 65
- C 70
- D 75
- E 80

Solution:

Since D and E are midpoints, $\triangle ADE$ has $\frac{1}{4}$ the area of $\triangle ABC$, namely 30, so trapezoid $EDBC$ has area $120 - 30 = 90$.

By the Angle Bisector Theorem, G divides BC with $BG = \frac{AB}{AB+AC} \cdot BC = \frac{5}{6}BC$, and likewise F divides DE so that $DF = \frac{5}{6}DE$. Because $FDBG$ and $EDBC$ share the same height, the area of $FDBG$ is $\frac{5}{6}$ of the area of $EDBC : \frac{5}{6} \cdot 90 = 75$.

Thus, the correct answer is **D**.

19. Let A be the set of positive integers that have no prime factors other than $2, 3,$ or $5.$ The infinite sum

$$\frac{1}{1}+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}+\frac{1}{6}+\frac{1}{8}+\frac{1}{9}+\frac{1}{10}+\frac{1}{12}+\frac{1}{15}+\frac{1}{16}+\frac{1}{18}+\frac{1}{20}+\cdots$$

of the reciprocals of all the elements of A can be expressed as $\frac{m}{n}$, where m and n are relatively prime positive integers. What is $m+n$?

A 16

B 17

C 19

D 23

E 36

Solution:

Each element of A is uniquely $2^i3^j5^k$ with $i, j, k \geq 0$, so summing all reciprocals factors as

$$\left(\sum_{i\geq 0}\frac{1}{2^i}\right)\left(\sum_{j\geq 0}\frac{1}{3^j}\right)\left(\sum_{k\geq 0}\frac{1}{5^k}\right)=\frac{1}{1-\frac{1}{2}}\cdot\frac{1}{1-\frac{1}{3}}\cdot\frac{1}{1-\frac{1}{5}}.$$

This equals $2\cdot\frac{3}{2}\cdot\frac{5}{4}=\frac{15}{4}$. With $\gcd(15,4)=1, m+n=15+4=19.$

Thus, the correct answer is **C**.

20. Triangle ABC is an isosceles right triangle with $AB = AC = 3$. Let M be the midpoint of hypotenuse $\overline{BC}$. Points I and E lie on sides $\overline{AC}$ and $\overline{AB}$, respectively, so that $AI > AE$ and $AIME$ is a cyclic quadrilateral. Given that triangle EMI has area 2, the length CI can be written as $\frac{a-\sqrt{b}}{c}$, where $a, b,$ and c are positive integers and b is not divisible by the square of any prime. What is the value of $a+b+c$?

- A 9
- B 10
- C 11
- D 12
- E 13

Solution:

Since $\triangle ABC$ is an isosceles right triangle, $CM = BM = \frac{3}{2}\sqrt{2}$ and the base angles at B, C are 45°. As $AIME$ is cyclic with right angle at A, angle $\angle IME = 90^\circ$. Let $x = CI$ and $y = BE$. By the Law of Cosines in $\triangle MCI$,

$$IM^2 = x^2 + \frac{9}{2} - 2 \cdot x \cdot \frac{3}{2}\sqrt{2} \cdot \cos 45^\circ = x^2 - 3x + \frac{9}{2},$$

and similarly $ME^2 = y^2 - 3y + \frac{9}{2}$.

The Pythagorean Theorem in right triangles EMI and IAE gives $IM^2 + ME^2 = (3-x)^2 + (3-y)^2$, which simplifies to $x + y = 3$. The area condition $\frac{1}{2}IM \cdot ME = 2$ means $IM^2 \cdot ME^2 = 16$. Substituting $y = 3 - x$ makes $ME^2 = x^2 - 3x + \frac{9}{2} = IM^2$, so $\left(x^2 - 3x + \frac{9}{2}\right)^2 = 16$, hence $x^2 - 3x + \frac{9}{2} = 4$, i.e. $x^2 - 3x + \frac{1}{2} = 0$.

Since $AI > AE$ forces $y > x$, we take the smaller root $x = \frac{3-\sqrt{7}}{2}$. Then $a + b + c = 3 + 7 + 2 = 12$.

Thus, the correct answer is **D**.

21. Which of the following polynomials has the greatest real root?

- A $x^{19} + 2018x^{11} + 1$
- B $x^{17} + 2018x^{11} + 1$
- C $x^{19} + 2018x^{13} + 1$
- D $x^{17} + 2018x^{13} + 1$
- E $2019x + 2018$

Solution:

Each polynomial in choices A–D has no positive root and exactly one negative root, which lies in $(-1, 0)$ (it is positive at 0 and negative at -1) and is increasing there. On the interval $(-1, 0)$, $x^{19} < x^{17}$ and $x^{13} < x^{11}$. Increasing a term makes the polynomial larger, which pushes its root to the left (smaller). So the smallest exponents give the greatest root, favoring choice B ($x^{17} + 2018x^{11} + 1$) over A, C, and D.

The linear choice E has root $-\frac{2018}{2019} = -\left(1 - \frac{1}{2019}\right)$, very close to -1; evaluating the polynomial of choice B there gives a negative value, so B's root lies to the right of E's. Hence B has the greatest real root.

Thus, the correct answer is **B**.

22. The solutions to the equations $z^2 = 4 + 4\sqrt{15}\,i$ and $z^2 = 2 + 2\sqrt{3}\,i$, where $i = \sqrt{-1}$, form the vertices of a parallelogram in the complex plane. The area of this parallelogram can be written in the form $p\sqrt{q} - r\sqrt{s}$, where p, q, r, and s are positive integers and neither q nor s is divisible by the square of any prime number. What is $p + q + r + s$?

- A 20
- B 21
- C 22
- D 23
- E 24

Solution:

Writing $z = a + bi$ with $(a + bi)^2 = 4 + 4\sqrt{15}\,i$ gives $a^2 - b^2 = 4$ and $2ab = 4\sqrt{15}$. Then $a^4 - 4a^2 - 60 = 0$, so $(a^2 - 10)(a^2 + 6) = 0$, yielding $a = \pm\sqrt{10}, b = \pm\sqrt{6}$. The vertices from the first equation are $\pm(\sqrt{10} + \sqrt{6}\,i)$. The same method on $z^2 = 2 + 2\sqrt{3}\,i$ gives $\pm(\sqrt{3} + i)$.

Applying the shoelace formula to $(\sqrt{10}, \sqrt{6}), (\sqrt{3}, 1), (-\sqrt{10}, -\sqrt{6}), (-\sqrt{3}, -1)$ gives area $6\sqrt{2} - 2\sqrt{10}$. Thus $p + q + r + s = 6 + 2 + 2 + 10 = 20$.

Thus, the correct answer is **A**.

23. In $\triangle PAT, \angle P = 36^\circ, \angle A = 56^\circ$, and $PA = 10$. Points U and G lie on sides $\overline{TP}$ and $\overline{TA}$, respectively, so that $PU = AG = 1$. Let M and N be the midpoints of segments $\overline{PA}$ and $\overline{UG}$, respectively. What is the degree measure of the acute angle formed by lines MN and PA?

A 76

B 77

C 78

D 79

E 80

Solution:

Extend PN through N to Q with $PN = NQ$. Since N is the midpoint of UG and of PQ, the quadrilateral $UPGQ$ is a parallelogram, so $GQ \parallel PT$ and $GQ = PU = 1 = AG$. Then $\angle QGA = 180^\circ - \angle T = \angle P + \angle A = 36^\circ + 56^\circ = 92^\circ$, and the isosceles triangle QGA gives $\angle QAG = \frac{1}{2}(180^\circ - 92^\circ) = 44^\circ$.

Because M, N are midpoints, MN is a midline of $\triangle QPA$, so $MN \parallel AQ$ and

$$\angle NMP = \angle QAP = \angle QAG + \angle GAP = 44^\circ + 56^\circ = 100^\circ.$$

The acute angle between line MN and PA is therefore $180^\circ - 100^\circ = 80^\circ$.

Thus, the correct answer is **E**.

24. Alice, Bob, and Carol play a game in which each of them chooses a real number between 0 and 1. The winner of the game is the one whose number is between the numbers chosen by the other two players. Alice announces that she will choose her number uniformly at random from all the numbers between 0 and 1, and Bob announces that he will choose his number uniformly at random from all the numbers between $\frac{1}{2}$ and $\frac{2}{3}$. Armed with this information, what number should Carol choose to maximize her chance of winning?

A $\frac{1}{2}$

B $\frac{13}{24}$

C $\frac{7}{12}$

D $\frac{5}{8}$

E $\frac{2}{3}$

Solution:

If $c \le \frac{1}{2}$, Carol beats Bob automatically, so she wins only if Alice is below c, probability $c \le \frac{1}{2}$. If $c \ge \frac{2}{3}$, she wins with probability $1 - c \le \frac{1}{3}$. Neither case exceeds $\frac{1}{2}$.

For $\frac{1}{2} < c < \frac{2}{3}$, the chance Bob's number exceeds c is $\frac{2/3-c}{2/3-1/2} = 4 - 6c$, so the probability Carol is above Alice and below Bob is $c(4-6c)$; the reverse ordering has probability $(1-c)(6c-3)$. Adding,

$$c(4-6c) + (1-c)(6c-3) = -12c^2 + 13c - 3.$$

This downward parabola is maximized at $c = \frac{13}{24}$, which lies in $\left(\frac{1}{2}, \frac{2}{3}\right)$, and its value exceeds $\frac{1}{2}$.

Thus, the correct answer is **B**.

25. For a positive integer n and nonzero digits a, b, and c, let A_n be the n-digit integer each of whose digits is equal to a; let B_n be the n-digit integer each of whose digits is equal to b; and let C_n be the $2n$-digit (not n-digit) integer each of whose digits is equal to c. What is the greatest possible value of $a + b + c$ for which there are at least two values of n such that $C_n - B_n = A_n^2$?

A 12

B 14

C 16

D 18

E 20

Solution:

Using $A_n = a \cdot \frac{10^n - 1}{9}$, $B_n = b \cdot \frac{10^n - 1}{9}$, and $C_n = c \cdot \frac{10^{2n} - 1}{9}$, the equation $C_n - B_n = A_n^2$ becomes, after dividing by $10^n - 1$ and clearing fractions,

$$(9c - a^2) \cdot 10^n = 9b - 9c - a^2.$$

For this to hold at two different n, the coefficient of 10^n must be zero, so $9c = a^2$ and hence $9b - 9c - a^2 = 0$.

Then $c = \frac{a^2}{9}$ and $b = 2c$. So $a \in \{3, 6, 9\}$ with $c \in \{1, 4, 9\}$ and $b \in \{2, 8, 18\}$; the case $b = 18$ is not a digit. The valid triples are $(a, b, c) = (3, 2, 1)$ and $(6, 8, 4)$, and indeed $4444 - 88 = 4356 = 66^2$. The greater digit sum is $6 + 8 + 4 = 18$.

Thus, the correct answer is **D**.

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