The CENTRE for EDUCATION
in MATHEMATICS and COMPUTING

cemc.uwaterloo.ca

Hypatia Contest

(Grade 11)

Thursday, April 4, 2024
(in North America and South America)

Friday, April 5, 2024
(outside of North America and South America)

UNIVERSITY OF WATERLOO

Time: 75 minutes

Do not open this booklet until instructed to do so.

Number of questions: 4 **Each question is worth 10 marks**

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7. No student may write more than one of the Fryer, Galois and Hypatia Contests in the same year.

1. At Radford Motors, 4050 trucks were sold. Of the trucks sold, 32% were white, 24% were grey, and 44% were black.

   (a) How many white trucks were sold?

   (b) If $\frac{1}{4}$ of the grey trucks sold were electric, how many trucks sold were both grey and electric?

   (c) In addition to the 4050 trucks that were sold, there were k unsold trucks, all of which were black. In total, 46% of all trucks, sold and unsold, were black. Determine the value of k.

2. For a positive 3-digit integer n, $f(n)$ is equal to the sum of n and the digits of n. For example, $f(351) = 351 + 3 + 5 + 1 = 360$.

   Note: The decimal representation of the 3-digit number abc is $a \cdot 10^2 + b \cdot 10 + c$. For example, $836 = 8 \cdot 10^2 + 3 \cdot 10 + 6$.

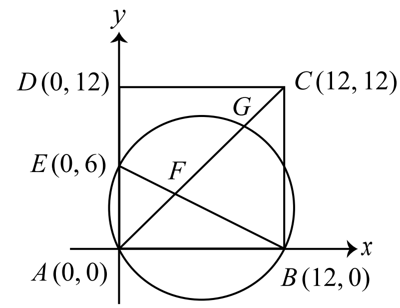
   (a) What is the value of $f(132)$?

   (b) If $f(n) = 175$, what is the value of n?

   (c) If $f(n) = 204$, determine all possible values of n.

3. In the diagram, $ABCD$ is a square with side length 12. The midpoint of AD is E, and BE intersects AC at F. The circle with diameter BE passes through A, and intersects AC at G.

Note: A circle with centre (h, k) and radius r has equation $(x-h)^2 + (y-k)^2 = r^2$.



(a) What are the coordinates of F?

(b) What is the area of $\triangle AEF$?

(c) Determine the area of quadrilateral $GDEF$.

4. A *Hewitt number* is a positive integer that is the sum of the cubes of three consecutive positive integers. The smallest Hewitt number is $1^3 + 2^3 + 3^3 = 36$.

(a) How many Hewitt numbers between 10 000 and 100 000 are divisible by 10?

(b) Determine how many of the smallest 2024 Hewitt numbers are divisible by 216.

(c) Consider the following statement:

> There are two distinct Hewitt numbers whose sum is equal to $9 \cdot 2^k$ for some positive integer k.

Show that this statement is true by finding two such Hewitt numbers or prove that it is false by demonstrating that there cannot be two such Hewitt numbers.

2024 Hypatia Contest (English)

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UNIVERSITY OF WATERLOO

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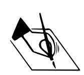
2. **FULL SOLUTION** parts indicated by 
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1. A game is played in which each throw of a ball lands in one of two holes: the closer hole or the farther hole. A throw landing in the closer hole scores 2 points, while a throw landing in the farther hole scores 5 points. A player's total score is equal to the sum of the scores on their throws.

   (a) Jasmin had 3 throws that each scored 2 points and 4 throws that each scored 5 points. What was Jasmin's total score?

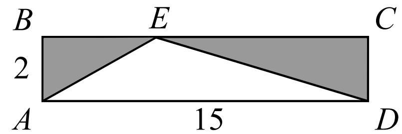
   (b) Sam had twice as many throws that scored 2 points as throws that scored 5 points. If Sam's total score was 36 points, how many throws did Sam take?

   (c) Tia had t throws that each scored 2 points and f throws that each scored 5 points. If Tia's total score was 37 points, determine all possible ordered pairs (t, f).

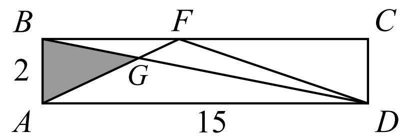
   (d) The game is changed so that each throw scores 6 or 21 points instead of 2 or 5. Explain whether or not it is possible to have a total score of 182 points.

2. In each question below, $ABCD$ is a rectangle with $AB = 2$ and $AD = 15$.

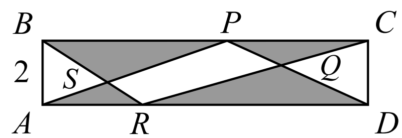
(a) Point E is on BC, as shown. What is the total area of the shaded regions?



(b) Point F is on BC, and BD intersects AF at G, as shown. If the area of $\triangle FGD$ is 5, what is the area of the shaded region?



(c) Point P is on BC and R is on AD. BR and AP intersect at S and PD and RC intersect at Q, as shown. If the area of $PQRS$ is 6, determine the total area of the shaded regions.



3. For any positive integer with three or more different, non-zero digits, let a *cousin* be defined as the result of switching two digits of the integer. For example, the integer 156 has three cousins:

- 516 (obtained by switching the 1st and 2nd digits),
- 651 (obtained by switching the 1st and 3rd digits), and
- 165 (obtained by switching the 2nd and 3rd digits).

(a) In no particular order, five of the six cousins of 6238 are listed below. Which cousin is missing from the list?

2638	6328
3268	6283
8236	

(b) In no particular order, the following list contains an original integer as well as all of its cousins. What is the original integer?

726 194	726 941	746 291	627 491
276 491	926 471	796 421	726 419
729 461	716 492	762 491	726 491
126 497	721 496	426 791	724 691

(c) Suppose that c and d are distinct, non-zero digits. The three-digit integer $cd3$ minus one of its cousins is equal to the three-digit integer $d95$. Determine the values of c and d and show that no other values are possible.

(d) Suppose that m and n are distinct, non-zero digits. The sum of the six cousins of the four-digit integer $mn97$ is equal to the five-digit integer $nmnm7$. Determine the values of m and n and show that no other values are possible.

4. The Great Math Company has a random integer generator which produces an integer from 1 to 9 inclusive, where each integer is generated with equal probability. Each member of the Multiplication Team uses this generator a certain number of times and then calculates the product of their integers.

(a) Amarpreet uses the generator 3 times. What is the probability that the product is a prime number?

(b) Braxton uses the generator 4 times. Determine the probability that the product is divisible by 5, but *not* divisible by 7.

(c) Camille uses the generator 2023 times. Let p be the probability that the product is *not* divisible by 6. Determine the ones digit of the integer equal to $p \times 9^{2023}$.

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Useful Fact:
It may be helpful to know that $2^n \geq n + 1$ for all positive integers n.

1. A *regular hexagon* is a polygon that has six sides with equal length and six interior angles with equal measure. In Figure 1, regular hexagon $ABCDEF$ has side length $2x$ and its vertices lie on the circle with centre O. The diagonals AD, BE and CF divide $ABCDEF$ into six congruent equilateral triangles.

   (a) In terms of x, what is the radius of the circle?

   (b) The midpoint of side AB is labelled M, as shown in Figure 2. In terms of x, what is the length of OM?

   (c) In terms of x, what is the area of hexagon $ABCDEF$?

   (d) The region that lies inside the circle and outside hexagon $ABCDEF$ is shaded, as shown in Figure 3. The area of this shaded region is 123. Rounded to the nearest tenth, determine the value of x.

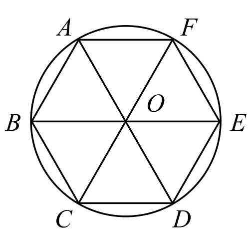

Figure 1

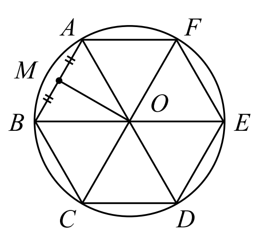

Figure 2

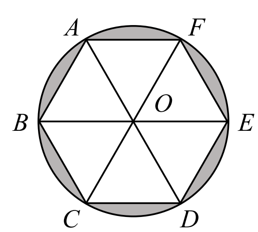

Figure 3

2. With 1 kg of muffin batter, exactly 24 mini muffins and 2 large muffins can be made. With 2 kg of muffin batter, exactly 36 mini muffins and 6 large muffins can be made.

(a) With 2 kg of muffin batter, exactly 48 mini muffins and n large muffins can also be made. What is the value of n?

(b) With x kg of muffin batter, exactly 84 mini muffins and 10 large muffins can be made. What is the value of x?

(c) Determine how many mini muffins can be made using the same amount of batter that is needed to make 7 large muffins.

3. A sequence is created in such a way that

- a real number is chosen as the first number in the sequence, and
- each of the following numbers in the sequence is generated by applying a function to the previous number in the sequence.

For example, if the first number in a sequence is 1 and the following numbers are generated by the function $x^2 - 5$, then the first three numbers in the sequence are $1, -4$ and 11 since $1^2 - 5 = -4$ and $(-4)^2 - 5 = 11$.

(a) The first number in a sequence is 3 and the sequence is generated by the function $x^2 - 3x + 1$. What are the first four numbers in the sequence?

(b) The number 7 is the third number in a sequence generated by the function $x^2 - 4x + 7$. What are all possible first numbers in the sequence?

(c) The first number in a sequence is c and the sequence is generated by the function $x^2 - 7x - 48$. If all numbers in the sequence are equal to c, determine all possible values of c.

(d) A sequence generated by the function $x^2 - 12x + 39$ alternates between two different numbers. That is, the sequence is $a, b, a, b, a, b, \ldots$, with $a \neq b$. Determine all possible values of a.

4. Every integer $N > 1$ can be written as $N = p_1^{a_1} p_2^{a_2} p_3^{a_3} \cdots p_k^{a_k}$, where k is a positive integer, $p_1 < p_2 < p_3 < \cdots < p_k$ are prime numbers, and $a_1, a_2, a_3, \ldots, a_k$ are positive integers. For example, $1400 = 2^3 5^2 7^1$.

The number of positive divisors of N is denoted by $f(N)$. It is known that

$$f(N) = (1 + a_1)(1 + a_2)(1 + a_3) \cdots (1 + a_k)$$

(a) How many positive divisors does 240 have? That is, what is the value of $f(240)$?

(b) Define an integer $N > 1$ to be *refactorable* if it is divisible by $f(N)$. For example, both 6 and 8 have 4 positive divisors, so 8 is refactorable and 6 is not refactorable. This is because 8 is divisible by 4, but 6 is not divisible by 4. Determine all refactorable numbers N with $f(N) = 6$.

(c) Determine the smallest refactorable number N with $f(N) = 256$.

(d) Show that for every integer $m > 1$, there exists a refactorable number N such that $f(N) = m$.

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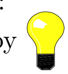
1. **SHORT ANSWER** parts indicated by 
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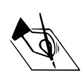
2. **FULL SOLUTION** parts indicated by 
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1. A company rents out various sized passenger vehicles according to the following table. For example, a group of $5, 6, 7$, or 8 people would need to rent a sports utility vehicle (SUV), which has a total cost of \$200.00. Unfortunately, the total cost to rent a van is missing from the table. In each case, the members of the group equally share the total cost to rent the vehicle.

Vehicle	Number of Passengers Required	Total Cost
Car	1 to 4	\$180.00
SUV	5 to 8	\$200.00
Van	9 to 12	

(a) If 4 people rent a car, what is the cost per person?

(b) If a group rents an SUV, what is the maximum possible cost per person?

(c) When a van is rented, the difference between the maximum cost per person and the minimum cost per person is \$6.00. Determine the total cost to rent a van.

2. Trapezoid $ABCD$ has vertices $A(0, 0)$, $B(12, 0)$, $C(11, 5)$, $D(2, 5)$.

(a) What is the area of trapezoid $ABCD$?

(b) The line passing through B and D intersects the y-axis at the point E. What are the coordinates of E?

(c) The sides AD and BC are extended to intersect at the point F. Determine the coordinates of F.

(d) Determine all possible points P that lie on the line passing through B and D, so that the area of $\triangle PAB$ is 42.

3. The sequence A, with terms $a_1, a_2, a_3, \ldots$, is defined by

$$a_n = 2^n, \text{ for } n \geq 1.$$

The sequence B, with terms $b_1, b_2, b_3, \ldots$, is defined by

$$b_1 = 1, \ b_2 = 1, \text{ and } b_n = b_{n-1} + 2b_{n-2}, \text{ for } n \geq 3.$$

For example, $b_3 = b_2 + 2b_1 = 1 + 2(1) = 3$.

In this question, the following facts may be helpful:

- A *geometric sequence* is a sequence in which each term after the first is obtained from the previous term by multiplying it by a non-zero constant called the common ratio. For example, $3, 6, 12$ is a geometric sequence with three terms and common ratio 2.

- The sum of the first n terms of a geometric sequence with first term a, and common ratio $r \neq 1$, equals $a\left(\dfrac{1-r^n}{1-r}\right)$.

(a) What are the 5^{th} terms for each sequence? That is, what are the values of a_5 and b_5?

(b) For some real numbers p and q, $b_n = p \cdot (a_n) + q \cdot (-1)^n$ for all $n \geq 1$. (You do not need to show this.) What are the values of p and q?

(c) Let S_n be the sum of the first n terms in sequence B. That is, $S_n = b_1 + b_2 + b_3 + \cdots + b_n$. Determine the smallest positive integer n that satisfies $S_n \geq 16^{2021}$.

4. In $\triangle XYZ$, the measure of $\angle XZY$ is $90°$. Also, $YZ = x$ cm, $XZ = y$ cm, and hypotenuse XY has length z cm. Further, the perimeter of $\triangle XYZ$ is P cm and the area of $\triangle XYZ$ is A cm^2.

(a) If $x = 20$ and $y = 21$, what are the values of A and P?

(b) If $z = 50$ and $A = 336$, what is the value of P?

(c) Determine all possible integer values of x, y and z for which $A = 3P$.

(d) Suppose that x, y and z are integers, that $P = 510$, and that $A = kP$ for some prime number k. Determine all possible values of k.

2021 Hypatia Contest (English)

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Hypatia Contest

(Grade 11)

Wednesday, April 15, 2020
(in North America and South America)

Thursday, April 16, 2020
(outside of North America and South America)

UNIVERSITY OF WATERLOO

Time: 75 minutes

Do not open this booklet until instructed to do so.

Number of questions: 4 **Each question is worth 10 marks**

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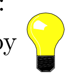
1. **SHORT ANSWER** parts indicated by 
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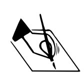
2. **FULL SOLUTION** parts indicated by 
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1. At a local grocery store, avocados are sold for \$5.00 per bag and mangoes for \$12.50 per box. A bag contains 6 avocados and a box contains 15 mangoes. Only a whole number of bags and a whole number of boxes can be purchased.

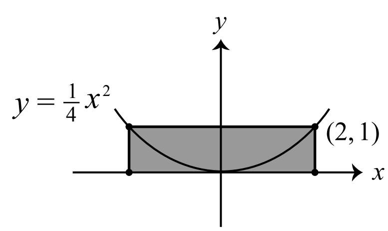
   (a) On Friday, a chef purchased 12 bags of avocados and some boxes of mangoes. If the total cost was \$135.00, how many boxes of mangoes were purchased?

   (b) On Saturdays only, there is a 10% discount on the price of a bag of avocados and a 20% discount on the price of a box of mangoes. What is the total cost for 8 bags of avocados and 4 boxes of mangoes on Saturdays?

   (c) On Monday, the chef needed 100 avocados and 70 mangoes. The chef purchased just enough bags and boxes. Determine how much the purchase cost her.

   (d) On Tuesday, the chef made special tarts that each required 1 avocado and 2 mangoes. If the chef spent *exactly* \$75.00 on avocados and mangoes, determine the greatest number of tarts that she could have made.

2. The parabola with equation $y = \frac{1}{4}x^2$ has its vertex at the origin and the y-axis as its axis of symmetry. For any point (p, q) on the parabola (not at the origin), we can form a *parabolic rectangle*. This rectangle will have one vertex at (p, q), a second vertex on the parabola, and the other two vertices on the x-axis. A parabolic rectangle with area 4 is shown.



   (a) A parabolic rectangle has one vertex at $(6, 9)$. What are the coordinates of the other three vertices?

   (b) What is the area of the parabolic rectangle having one vertex at $(-3, 0)$?

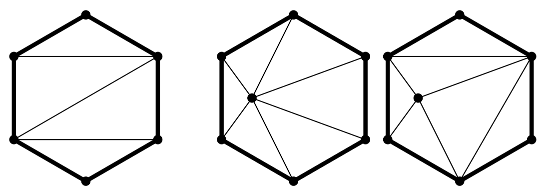
   (c) Determine the areas of the two parabolic rectangles that have a side length of 36.

   (d) Determine the area of the parabolic rectangle whose length and width are equal.

3. A *triangulation* of a regular polygon is a division of its interior into triangular regions. In such a division, each vertex of each triangle is either a vertex of the polygon or an interior point of the polygon. In a triangulation of a regular polygon with $n \geq 3$ vertices and $k \geq 0$ interior points with no three of these $n + k$ points lying on the same line,

- no two line segments connecting pairs of these points cross anywhere except at their endpoints, and
- each interior point is a vertex of at least one of the triangular regions.

Every regular polygon has at least one triangulation. The number of triangles formed by any triangulation of a regular polygon with n vertices and k interior points is constant and is denoted $T(n, k)$. For example, in every possible triangulation of a regular hexagon and one interior point, there are exactly 6 triangles. That is, $T(6, 1) = 6$.



$T(6, 0) = 4$ $\qquad$ $T(6, 1) = 6$

(a) What is the value of $T(3, 2)$?

(b) Determine the value of $T(4, 100)$.

(c) Determine the value of n for which $T(n, n) = 2020$.

4. Let x_0 be a non-negative integer. For each integer $i \geq 0$, define $x_{i+1} = (x_i)^2 + 1$.

(a) Show that $x_2 - x_0$ is even for all possible values of x_0.

(b) Show that $x_{2026} - x_{2020}$ is divisible by 10 for all possible values of x_0.

(c) Parsa chooses an integer n with $1 \leq n \leq 100$ at random and sets $x_0 = n$. Determine the probability that $x_{115} - 110$ is divisible by 105.

2020 Hypatia Contest (English)

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Hypatia Contest

(Grade 11)

Wednesday, April 10, 2019
(in North America and South America)

Thursday, April 11, 2019
(outside of North America and South America)

UNIVERSITY OF WATERLOO

Time: 75 minutes

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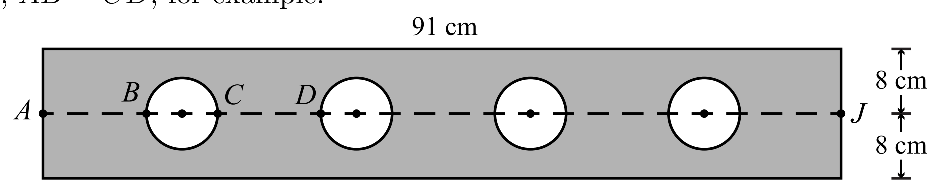
1. A rectangular piece of metal measures 91 cm by 16 cm. Four identical circular discs are punched out of this piece of metal. The centres of the circular holes are on the midline of the rectangle, AJ, as shown. These four holes are equally spaced along the piece of metal. That is, $AB = CD$, for example.



(a) If the radius of each hole is 2 cm, what is the distance along the midline between adjacent holes (i.e. what is the length of CD)?

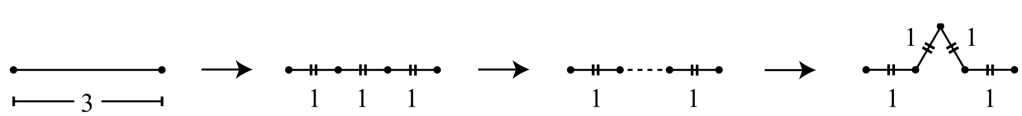
(b) If the distance along the midline between adjacent holes is equal to the radius of each hole, what is the radius of each hole?

(c) Show why the fact that holes must be circles means that the distance between adjacent holes cannot be 5 cm.

2. A *bump* can be added to any line segment through the following process:

- break the segment into three segments of equal length,
- remove the middle segment,
- add an equilateral triangular shaped *bump* with each side length equal to the removed segment.

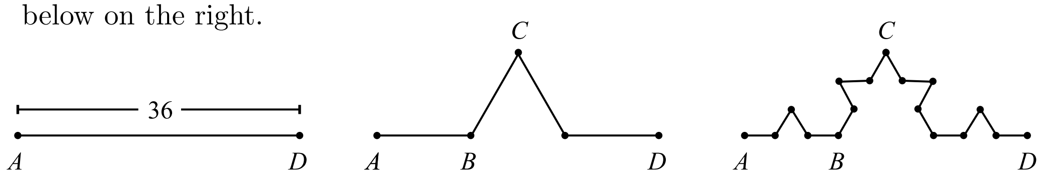
The series of diagrams below shows a *bump* being added to a line segment of length 3, transforming it into a path of length 4.



(a) A line segment has length 21. How long will the path be after a bump is added?

(b) A path with exactly one bump has length 240. How long was the original line segment?

(c) Lin starts with a line segment that has length 36 and adds a bump to it. She then adds bumps to each line segment of that path. The resulting figure is shown below on the right.



What is the total path length of the resulting figure?

(d) Ann starts with a line segment having length equal to some positive integer n and adds a bump to it resulting in Path 1. Ann then adds bumps to each line segment of Path 1 resulting in Path 2. She continues this process to create Path 3, Path 4, and finally Path 5. If the length of Path 5 is an integer, determine the smallest possible value of n.

3. The *arithmetic mean* of two positive real numbers x and y is half the sum of the two numbers, or $\dfrac{x+y}{2}$. The *geometric mean* of two positive real numbers x and y is the square root of the product of the two numbers, or $\sqrt{xy}$.

(a) What are the arithmetic and geometric means of 36 and 64?

(b) Determine a pair of positive real numbers whose arithmetic mean is 13 and geometric mean is 12.

(c) For two positive integers x and y, the arithmetic mean minus the geometric mean is equal to 1. Determine, with justification, all such pairs (x, y) where $x < y \leq 50$.

4. (a) Suppose that c is a real number. Solve the following system of equations for x and y in terms of c:

$$
\begin{aligned}
3x + 4y &= 10 \\
5x + 6y &= c
\end{aligned}
$$

(b) Determine all integers d for which the system of equations

$$
\begin{aligned}
x + 2y &= 3 \\
4x + dy &= 6
\end{aligned}
$$

has a solution (x, y), where x and y are integers.

(c) Determine a positive integer k for which there are exactly 8 integers n for which the system of equations

$$
\begin{aligned}
(9n+6)x - (3n+2)y &= 3n^2 + 6n + (3k+5) \\
(6n+4)x + (3n^2+2n)y &= -n^2 + (2k+2)
\end{aligned}
$$

has a solution (x, y), where x and y are integers.

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Hypatia Contest

(Grade 11)

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(in North America and South America)

Friday, April 13, 2018
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UNIVERSITY OF WATERLOO

Time: 75 minutes

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1. Mr. Singh gives his students a test each week.

   (a) Aneesh's scores on the first six tests were 17, 13, 20, 12, 18, and 10. What was the average (mean) of his test scores?

   (b) Jon scored 17 and 12 on his first two tests. After the third test, his average (mean) score was 14. What was his score on the third test?

   (c) After the first six tests, Dina had an average (mean) test score of 14. On each of the next n tests, Dina's score was 20 out of 20. After all of these tests, her average (mean) test score was 18. Determine the value of n.

2. Each day, Jessica drives from Botown to Aville, a distance of 120 km. During the drive, her car's navigation system constantly updates the estimated time of arrival (ETA) at Aville. The car predicts the ETA by assuming that Jessica will drive the remaining distance at 80 km/h.

   (a) On Monday, Jessica drove at 90 km/h. How many minutes did it take Jessica to drive from Botown to Aville?

   (b) On Tuesday, Jessica left Botown at 7:00 a.m.. What was the ETA displayed by her car at 7:00 a.m.?

   (c) On Tuesday, Jessica drove at 90 km/h. Determine the ETA displayed by her car at 7:16 a.m..

   (d) On Wednesday, Jessica noted the ETA predicted by her car when she left Botown. She travelled the first part of the trip at 50 km/h and travelled the rest of the way at 100 km/h. Jessica arrived in Aville at the ETA predicted by her car when she left Botown. Determine the distance that she drove at a speed of 100 km/h.

3. A sequence $T_1, T_2, T_3, \ldots$ is defined by $T_1 = 1$, $T_2 = 2$, and each term after the second is equal to 1 more than the product of all previous terms in the sequence. That is, $T_{n+1} = 1 + T_1T_2T_3 \cdots T_n$ for all integers $n \geq 2$. For example, $T_3 = 1 + T_1T_2 = 3$.

(a) What is the value of T_5?

(b) Prove that $T_{n+1} = T_n^2 - T_n + 1$ for all integers $n \geq 2$.

(c) Prove that $T_n + T_{n+1}$ is a factor of $T_nT_{n+1} - 1$ for all integers $n \geq 2$.

(d) Prove that T_{2018} is not a perfect square.

4. (a) Consider the two parabolas defined by the equations $y = x^2 - 8x + 17$ and $y = -x^2 + 4x + 7$.

(i) Determine the coordinates of the vertices V_1 and V_2 of these two parabolas.

(ii) Suppose that these two parabolas intersect at the points P and Q. Explain why the quadrilateral V_1PV_2Q is a parallelogram.

(b) The two parabolas defined by the equations $y = -x^2 + bx + c$ and $y = x^2$ have vertices V_3 and V_4, respectively. For some values of b and c, these parabolas intersect at the points R and S.

(i) Determine all pairs (b, c) for which the points R and S exist and the points V_3, V_4, R, S are distinct.

(ii) Determine all pairs (b, c) for which the points R and S exist, the points V_3, V_4, R, S are distinct, and quadrilateral V_3RV_4S is a rectangle.

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UNIVERSITY OF WATERLOO

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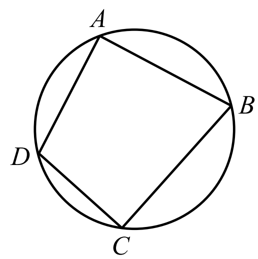
1. A *cyclic quadrilateral* is a quadrilateral whose four vertices lie on some circle. In a cyclic quadrilateral, opposite angles add to 180°. In the diagram, $ABCD$ is a cyclic quadrilateral. Therefore, $\angle ABC + \angle ADC = 180° = \angle BAD + \angle BCD$.



(a) In Figure A below, $ABCD$ is a cyclic quadrilateral. If $\angle BAD = 88°$, what is the value of u?

(b) In Figure B, $PQRS$ and $STQR$ are cyclic quadrilaterals. If $\angle STQ = 58°$, what is the value of x and what is the value of y?

(c) In Figure C, $JKLM$ is a cyclic quadrilateral with $JK = KL$ and $JL = LM$. If $\angle KJL = 35°$, what is the value of w?

(d) In Figure D, $DEFG$ is a cyclic quadrilateral. FG is extended to H, as shown. If $\angle DEF = z°$, determine the measure of $\angle DGH$ in terms of z.

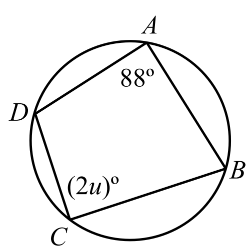


Figure A

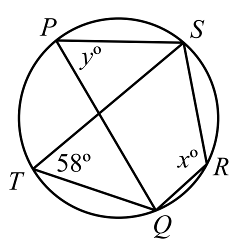


Figure B

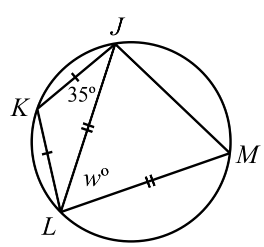


Figure C

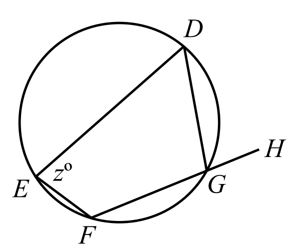


Figure D

2. A list of integers is written in a table, row after row from left to right. Row 1 has the integer 1. Row 2 has the integers $1, 2$ and 3. Row n has the consecutive integers beginning at 1 and ending at the n^{th} odd integer. In the table, the 9^{th} integer to be written is 5, and it appears at the end of Row 3. In general, after having completed n rows, a total of n^2 integers have been written.

Row 1	1						
Row 2	1	2	3				
Row 3	1	2	3	4	5		
Row 4	1	2	3	4	5	6	7
$\vdots$							

(a) What is the 25^{th} integer written in the table and in which row does the 25^{th} integer appear?

(b) What is the 100^{th} integer written in the table?

(c) What is the 2017^{th} integer written in the table?

(d) In how many of the first 200 rows does the integer 96 appear?

3. (a) The line $y = -15$ intersects the parabola with equation $y = -x^2 + 2x$ at two points. What are the coordinates of these two points of intersection?

(b) A line intersects the parabola with equation $y = -x^2 - 3x$ at $x = 4$ and at $x = a$. This line intersects the y-axis at $(0, 8)$. Determine the value of a.

(c) A line intersects the parabola with equation $y = -x^2 + kx$ at $x = p$ and at $x = q$ with $p \neq q$. Determine the y-intercept of this line.

(d) For all $k \neq 0$, the curve $x = \frac{1}{k^3}y^2 + \frac{1}{k}y$ intersects the parabola with equation $y = -x^2 + kx$ at $(0, 0)$ and at a second point T whose coordinates depend on k. All such points T lie on a parabola. Determine the equation of this parabola.

4. A positive integer is called an *n-digit zigzag number* if

- $3 \leq n \leq 9$,
- the number's digits are exactly $1, 2, \ldots, n$ (without repetition), and
- for each group of three adjacent digits, either the middle digit is greater than each of the other two digits or the middle digit is less than each of the other two digits.

For example, 52314 is a 5-digit zigzag number but 52143 is not.

(a) What is the largest 9-digit zigzag number?

(b) Let $G(n, k)$ be the number of n-digit zigzag numbers with first digit k and second digit greater than k. Let $L(n, k)$ be the number of n-digit zigzag numbers with first digit k and second digit less than k.

(i) Show that $G(6, 3) = L(5, 3) + L(5, 4) + L(5, 5)$.

(ii) Show that

$$G(6, 1) + G(6, 2) + G(6, 3) + G(6, 4) + G(6, 5) + G(6, 6)$$

equals

$$L(6, 1) + L(6, 2) + L(6, 3) + L(6, 4) + L(6, 5) + L(6, 6).$$

(c) Determine the number of 8-digit zigzag numbers.

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- Find your school's contest results

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Hypatia Contest

(Grade 11)

Wednesday, April 13, 2016
(in North America and South America)

Thursday, April 14, 2016
(outside of North America and South America)

UNIVERSITY OF
WATERLOO

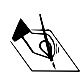
Time: 75 minutes

Do not open this booklet until instructed to do so.

Number of questions: 4 **Each question is worth 10 marks**

Calculators are allowed, with the following restriction: you may not use a device that has internet access, that can communicate with other devices, or that contains previously stored information. For example, you may not use a smartphone or a tablet.

Parts of each question can be of two types:

1. **SHORT ANSWER** parts indicated by 
   - worth 2 or 3 marks each
   - full marks given for a correct answer which is placed in the box
   - **part marks awarded only if relevant work** is shown in the space provided
2. **FULL SOLUTION** parts indicated by 
   - worth the remainder of the 10 marks for the question
   - **must be written in the appropriate location** in the answer booklet
   - marks awarded for completeness, clarity, and style of presentation
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WRITE ALL ANSWERS IN THE ANSWER BOOKLET PROVIDED.

- Extra paper for your finished solutions supplied by your supervising teacher must be inserted into your answer booklet. Write your name, school name, and question number on any inserted pages.
- Express calculations and answers as exact numbers such as $\pi + 1$ and $\sqrt{2}$, etc., rather than as $4.14\ldots$ or $1.41\ldots$, except where otherwise indicated.

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The name, grade, school and location of some top-scoring students will be published on our website, cemc.uwaterloo.ca. In addition, the name, grade, school and location, and score of some top-scoring students may be shared with other mathematical organizations for other recognition opportunities.

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3. For questions marked (lightbulb icon), place your answer in the appropriate box in the answer booklet and **show your work**.
4. For questions marked (pencil icon), provide a well-organized solution in the answer booklet. Use mathematical statements and words to explain all of the steps of your solution. Work out some details in rough on a separate piece of paper before writing your finished solution.
5. Diagrams are *not* drawn to scale. They are intended as aids only.
6. While calculators may be used for numerical calculations, other mathematical steps must be shown and justified in your written solutions and specific marks may be allocated for these steps. For example, while your calculator might be able to find the x-intercepts of the graph of an equation like $y = x^3 - x$, you should show the algebraic steps that you used to find these numbers, rather than simply writing these numbers down.
7. No student may write more than one of the Fryer, Galois and Hypatia Contests in the same year.

1. Raisins are sold by the scoop, cup, jar, basket, or tub in the following proportions: 5 scoops of raisins fill 1 jar, 3 scoops of raisins fill 1 cup, 5 baskets of raisins fill 2 tubs, and 30 jars of raisins fill 1 tub.

   (a) How many tubs of raisins fill 30 baskets?

   (b) How many cups of raisins fill 6 jars?

   (c) Determine how many cups of raisins fill 1 basket.

2. If a line segment is drawn from the centre of a circle to the midpoint of a chord, it is perpendicular to that chord. For example, in Figure 1, OM is perpendicular to chord AB.

   If a line segment is drawn from the centre of a circle and is perpendicular to a chord, it passes through the midpoint of that chord. For example, in Figure 2, $PR = QR$.

Figure 1

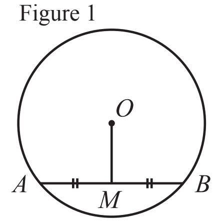
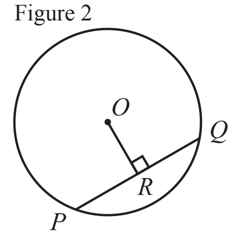
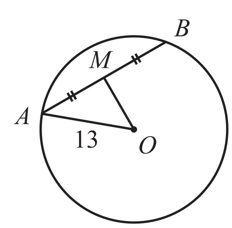


Figure 2

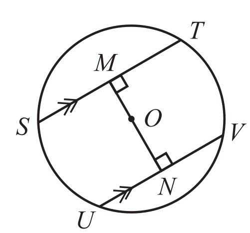


   (a) In the diagram, a circle with radius 13 has a chord AB with length 10. If M is the midpoint of AB, what is the length of OM?



   (b) In a circle with radius 25, a chord is drawn so that its perpendicular distance from the centre of the circle is 7. What is the length of this chord?

   (c) In the diagram, the radius of the circle is 65. Two parallel chords ST and UV are drawn so that the perpendicular distance between the chords is 72 ($MN = 72$). If MN passes through the centre of the circle O, and ST has length 112, determine the length of UV.



3. For a positive integer n, $f(n)$ is defined as the exponent of the largest power of 3 that divides n.
For example, $f(126) = 2$ since $126 = 3^2 \times 14$ so 3^2 divides 126, but 3^3 does not.

(a) What is the value of $f(405)$?

(b) What is the value of $f(1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8 \times 9 \times 10)$?

(c) Let N be the positive integer equal to $\dfrac{100!}{50!20!}$. Determine the value of $f(N)$.
(Note: If m is a positive integer, $m!$ represents the product of the integers from 1 to m, inclusive. For example, $5! = 1 \times 2 \times 3 \times 4 \times 5 = 120$.)

(d) Given that $f(a) = 8$ and $f(b) = 7$, determine all possible values of $f(a + b)$.

4. Erin's Pizza (EP) and Lino's Pizza (LP) are located next door to each other. Each day, each of 100 customers buys one whole pizza from one of the restaurants. The price of a pizza at each restaurant is set each day and is always a multiple of 10 cents. If the two restaurants charge the same price, half of the 100 customers will go to each restaurant. For every 10 cents that one restaurant's price is higher than the other restaurant's price, it loses one customer to the other restaurant. The cost for each restaurant to make a pizza is \$5.00.

As an example, if EP charges \$8.00 per pizza and LP charges \$9.00 per pizza, the number of customers and the resulting profit for each restaurant is shown in the table below.

Restaurant	Price per pizza	Number of customers	Profit
EP	\$8.00	$50 + 10 = 60$	$60 \times (\$8.00 - \$5.00) = \$180$
LP	\$9.00	$50 - 10 = 40$	$40 \times (\$9.00 - \$5.00) = \$160$

(a) On Monday, EP charges \$7.70 for a pizza and LP charges \$9.30.
  (i) How many customers does LP have?
  (ii) What is LP's total profit?

(b) EP sets its price first and then LP sets its price. On Tuesday, EP charges \$7.20 per pizza. What should LP's price be in order to maximize its profit?

(c) On Wednesday, EP realizes what LP is doing: LP is maximizing its profit by setting its price after EP's price is set. EP continues to set its price first and sets a price that is a multiple of 20 cents. LP's price is still a multiple of 10 cents and the number of customers at each restaurant still follows the rule above. Determine the two prices that EP could charge in order to maximize its profit. State LP's profit in each case.

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Hypatia Contest

(Grade 11)

Thursday, April 16, 2015
(in North America and South America)

Friday, April 17, 2015
(outside of North America and South America)

UNIVERSITY OF WATERLOO

Time: 75 minutes

Do not open this booklet until instructed to do so.

Number of questions: 4 **Each question is worth 10 marks**

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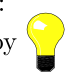
1. **SHORT ANSWER** parts indicated by 
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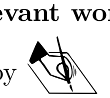
2. **FULL SOLUTION** parts indicated by 
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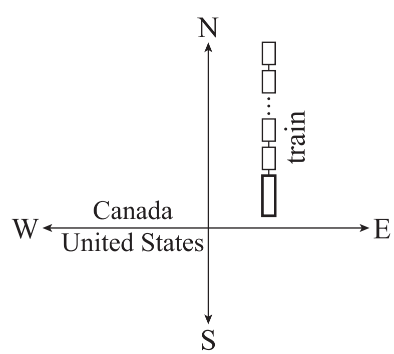
1. Each Hypatia Railway train has one engine car followed by some boxcars in a straight line. The distance between consecutive boxcars is 2 m. The distance between the engine car and the first boxcar is also 2 m. The engine car is 26 m in length and each boxcar is 15 m in length. The total length of a train is the distance from the front of the engine car to the end of the last boxcar.

   (a) What is the total length of a train with 10 boxcars?

   (b) A train has a total length of 2015 m. How many boxcars does the train have?

   (c) In the diagram, a southbound train with 14 boxcars crosses the border between Canada and the United States at a speed of 1.6 m/s. Determine the length of time in seconds during which a portion of the train is in Canada and a portion is in the United States at the same time.



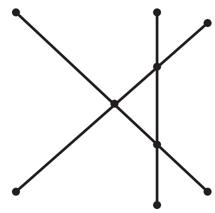
2. In the questions below, A, B, M, N, P, Q, and R are non-zero digits.

   (a) A two-digit positive integer AB equals $10A + B$. For example, $37 = 10 \times 3 + 7$. If $AB - BA = 72$, what is the positive integer AB?

   (b) A two-digit positive integer MN is given. Explain why it is not possible that $MN - NM = 80$.

   (c) A three-digit positive integer PQR equals $100P + 10Q + R$. If $P > R$, determine the number of possible values of $PQR - RQP$.

3. Consider n line segments, where each pair of line segments intersect at a different point, and not at an endpoint of any of the n line segments. Let $T(n)$ be the sum of the number of intersection points and the number of endpoints of the line segments. For example, $T(1) = 2$ and $T(2) = 5$. The diagram below illustrates that $T(3) = 9$.



(a) What do $T(4)$ and $T(5)$ equal?

(b) Express $T(n) - T(n-1)$ in terms of n.

(c) Determine all possible values of n such that $T(n) = 2015$.

4. Let $\gcd(a, b)$ represent the greatest common divisor of the two positive integers a and b. For example, $\gcd(18, 45) = 9$ since 9 is the largest positive integer that divides both 18 and 45.
The function $P(n)$ is defined to equal the sum of the n greatest common divisors, $\gcd(1, n), \gcd(2, n), \ldots, \gcd(n, n)$. For example:

$$\begin{aligned} P(6) &= \gcd(1,6) + \gcd(2,6) + \gcd(3,6) + \gcd(4,6) + \gcd(5,6) + \gcd(6,6) \\ &= 1 + 2 + 3 + 2 + 1 + 6 \\ &= 15 \end{aligned}$$

Note: You may use the fact that $P(ab) = P(a)P(b)$ for all positive integers a and b with $\gcd(a, b) = 1$.

(a) What is the value of $P(125)$?

(b) If r and s are different prime numbers, prove that $P(r^2 s) = r(3r - 2)(2s - 1)$.

(c) If r and s are different prime numbers, prove that $P(r^2 s)$ can never be equal to a power of a prime number (that is, can never equal t^n for some prime number t and positive integer n).

(d) Determine, with justification, two positive integers m for which $P(m) = 243$.

2015 Hypatia Contest (English)

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Hypatia Contest

(Grade 11)

Wednesday, April 16, 2014
(in North America and South America)

Thursday, April 17, 2014
(outside of North America and South America)

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Time: 75 minutes | **Number of questions: 4**
Calculators are permitted | **Each question is worth 10 marks**

Parts of each question can be of two types:

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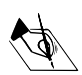
2. **FULL SOLUTION** parts indicated by 
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5. Diagrams are *not* drawn to scale. They are intended as aids only.

1. For real numbers a and b with $a \geq 0$ and $b \geq 0$, the operation $\odot$ is defined by

$$a \odot b = \sqrt{a + 4b}.$$

For example, $5 \odot 1 = \sqrt{5 + 4(1)} = \sqrt{9} = 3$.

(a) What is the value of $8 \odot 7$?

(b) If $16 \odot n = 10$, what is the value of n?

(c) Determine the value of $(9 \odot 18) \odot 10$.

(d) With justification, determine all possible values of k such that $k \odot k = k$.

2. Each week, the MathTunes Music Store releases a list of the Top 200 songs. A new song "Recursive Case" is released in time to make it onto the Week 1 list. The song's position, P, on the list in a certain week, w, is given by the equation $P = 3w^2 - 36w + 110$. The week number w is always a positive integer.

(a) What position does the song have on week 1?

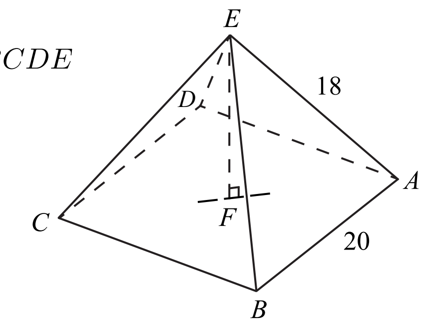
(b) Artists want their song to reach the best position possible. The closer that the position of a song is to position #1, the better the position.

(i) What is the best position that the song "Recursive Case" reaches?

(ii) On what week does this song reach its best position?

(c) What is the last week that "Recursive Case" appears on the Top 200 list?

3. A pyramid $ABCDE$ has a square base $ABCD$ of side length 20. Vertex E lies on the line perpendicular to the base that passes through F, the centre of the base $ABCD$. It is given that $EA = EB = EC = ED = 18$.



(a) Determine the surface area of the pyramid $ABCDE$ including its base.

(b) Determine the height EF of the pyramid.

(c) G and H are the midpoints of ED and EA, respectively. Determine the area of the quadrilateral $BCGH$.

4. The triple of positive integers (x, y, z) is called an Almost Pythagorean Triple (or APT) if $x > 1$ and $y > 1$ and $x^2 + y^2 = z^2 + 1$. For example, (5, 5, 7) is an APT.

(a) Determine the values of y and z so that $(4, y, z)$ is an APT.

(b) Prove that for any triangle whose side lengths form an APT, the area of the triangle is not an integer.

(c) Determine two 5-tuples (b, c, p, q, r) of positive integers with $p \geq 100$ for which $(5t + p, bt + q, ct + r)$ is an APT for all positive integers t.

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Hypatia Contest

(Grade 11)

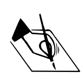
Thursday, April 18, 2013
(in North America and South America)

Friday, April 19, 2013
(outside of North America and South America)

Do not open this booklet until instructed to do so.

Time: 75 minutes | **Number of questions:** 4
Calculators are permitted | **Each question is worth 10 marks**

Parts of each question can be of two types:

1. **SHORT ANSWER** parts indicated by 
   - worth 2 or 3 marks each
   - full marks given for a correct answer which is placed in the box
   - **part marks awarded only if relevant work** is shown in the space provided
2. **FULL SOLUTION** parts indicated by 
   - worth the remainder of the 10 marks for the question
   - **must be written in the appropriate location** in the answer booklet
   - marks awarded for completeness, clarity, and style of presentation
   - a correct solution poorly presented will not earn full marks

WRITE ALL ANSWERS IN THE ANSWER BOOKLET PROVIDED.

- Extra paper for your finished solutions supplied by your supervising teacher must be inserted into your answer booklet. Write your name, school name, and question number on any inserted pages.
- Express calculations and answers as exact numbers such as $\pi + 1$ and $\sqrt{2}$, etc., rather than as $4.14\ldots$ or $1.41\ldots$, except where otherwise indicated.

Do not discuss the problems or solutions from this contest online for the next 48 hours.

The name, grade, school and location of some top-scoring students will be published on our Web site, http://www.cemc.uwaterloo.ca. In addition, the name, grade, school and location, and score of some top-scoring students may be shared with other mathematical organizations for other recognition opportunities.

TIPS:

1. Please read the instructions on the front cover of this booklet.
2. Write all answers in the answer booklet provided.
3. For questions marked , place your answer in the appropriate box in the answer booklet and **show your work**.
4. For questions marked , provide a well-organized solution in the answer booklet. Use mathematical statements and words to explain all of the steps of your solution. Work out some details in rough on a separate piece of paper before writing your finished solution.
5. Diagrams are *not* drawn to scale. They are intended as aids only.

1. At the JK Mall grand opening, some lucky shoppers are able to participate in a money giveaway. A large box has been filled with many \$5, \$10, \$20, and \$50 bills. The lucky shopper reaches into the box and is allowed to pull out one handful of bills.

   (a) Rad pulls out at least two bills of each type and his total sum of money is \$175. What is the total number of bills that Rad pulled out?

   (b) Sandy pulls out exactly five bills and notices that she has at least one bill of each type. What are the possible sums of money that Sandy could have?

   (c) Lino pulls out six or fewer bills and his total sum of money is \$160. There are exactly four possibilities for the number of each type of bill that Lino could have. Determine these four possibilities.

2. A parabola has equation $y = (x - 3)^2 + 1$.

   (a) What are the coordinates of the vertex of the parabola?

   (b) A new parabola is created by translating the original parabola 3 units to the left and 3 units up. What is the equation of the translated parabola?

   (c) Determine the coordinates of the point of intersection of these two parabolas.

   (d) The parabola with equation $y = ax^2 + 4$, $a < 0$, touches the parabola with equation $y = (x - 3)^2 + 1$ at exactly one point. Determine the value of a.

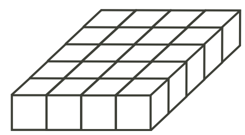
3. A sequence of m P's and n Q's with $m > n$ is called *non-predictive* if there is some point in the sequence where the number of Q's counted from the left is greater than or equal to the number of P's counted from the left.
For example, if $m = 5$ and $n = 2$ the sequence PPQQPPP is non-predictive because in counting the first four letters from the left, the number of Q's is equal to the number of P's. Also, the sequence QPPPQPP is non-predictive because in counting the first letter from the left, the number of Q's is greater than the number of P's.

(a) If $m = 7$ and $n = 2$, determine the number of non-predictive sequences that begin with P.

(b) Suppose that $n = 2$. Show that for every $m > 2$, the number of non-predictive sequences that begin with P is equal to the number of non-predictive sequences that begin with Q.

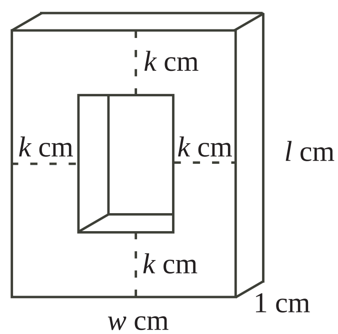
(c) Determine the number of non-predictive sequences with $m = 10$ and $n = 3$.

4. (a) Twenty cubes, each with edge length 1 cm, are placed together in 4 rows of 5. What is the surface area of this rectangular prism?



(b) A number of cubes, each with edge length 1 cm, are arranged to form a rectangular prism having height 1 cm and a surface area of 180 cm^2. Determine the number of cubes in the rectangular prism.

(c) A number of cubes, each with edge length 1 cm, are arranged to form a rectangular prism having length l cm, width w cm, and thickness 1 cm. A frame is formed by removing a rectangular prism with thickness 1 cm located k cm from each of the sides of the original rectangular prism, as shown. Each of l, w and k is a positive integer. If the frame has surface area 532 cm^2, determine all possible values for l and w such that $l \geq w$.



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Hypatia Contest

(Grade 11)

Thursday, April 12, 2012

(in North America and South America)

Friday, April 13, 2012

(outside of North America and South America)

STRONGER COMMUNITIES TOGETHER™

Do not open this booklet until instructed to do so.

Time: 75 minutes
Calculators are permitted

Number of questions: 4
Each question is worth 10 marks

Parts of each question can be of two types:

1. **SHORT ANSWER** parts indicated by
   - worth 2 or 3 marks each
   - full marks given for a correct answer which is placed in the box
   - **part marks awarded only if relevant work** is shown in the space provided

2. **FULL SOLUTION** parts indicated by
   - worth the remainder of the 10 marks for the question
   - **must be written in the appropriate location** in the answer booklet
   - marks awarded for completeness, clarity, and style of presentation
   - a correct solution poorly presented will not earn full marks

WRITE ALL ANSWERS IN THE ANSWER BOOKLET PROVIDED.

- Extra paper for your finished solutions supplied by your supervising teacher must be inserted into your answer booklet. Write your name, school name, and question number on any inserted pages.
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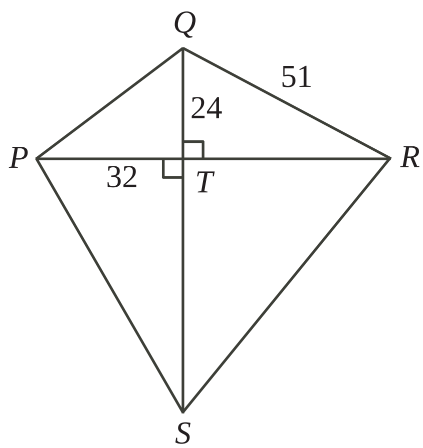
Do not discuss the problems or solutions from this contest online for the next 48 hours.

The name, grade, school and location of some top-scoring students will be published in the FGH Results on our Web site, http://www.cemc.uwaterloo.ca.

TIPS:

1. Please read the instructions on the front cover of this booklet.
2. Write all answers in the answer booklet provided.
3. For questions marked [lightbulb], place your answer in the appropriate box in the answer booklet and **show your work**.
4. For questions marked [pencil], provide a well-organized solution in the answer booklet. Use mathematical statements and words to explain all of the steps of your solution. Work out some details in rough on a separate piece of paper before writing your finished solution.
5. Diagrams are *not* drawn to scale. They are intended as aids only.

1. Quadrilateral $PQRS$ is constructed with $QR = 51$, as shown. The diagonals of $PQRS$ intersect at 90° at point T, such that $PT = 32$ and $QT = 24$.



(a) Calculate the length of PQ.

(b) Calculate the area of $\triangle PQR$.

(c) If $QS : PR = 12 : 11$, determine the perimeter of quadrilateral $PQRS$.

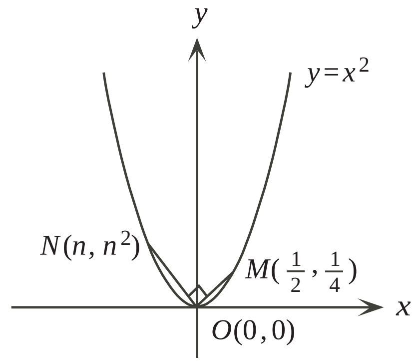
2. (a) Determine the value of $(a+b)^2$, given that $a^2 + b^2 = 24$ and $ab = 6$.

(b) If $(x+y)^2 = 13$ and $x^2 + y^2 = 7$, determine the value of xy.

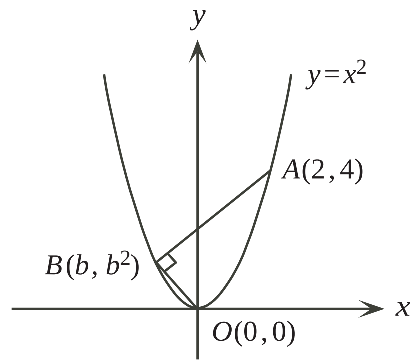
(c) If $j + k = 6$ and $j^2 + k^2 = 52$, determine the value of jk.

(d) If $m^2 + n^2 = 12$ and $m^4 + n^4 = 136$, determine all possible values of mn.

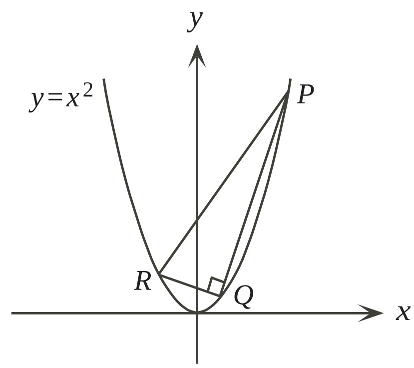
3. (a) Points $M(\frac{1}{2}, \frac{1}{4})$ and $N(n, n^2)$ lie on the parabola with equation $y = x^2$, as shown. Determine the value of n such that $\angle MON = 90°$.



(b) Points $A(2, 4)$ and $B(b, b^2)$ are the endpoints of a chord of the parabola with equation $y = x^2$, as shown. Determine the value of b so that $\angle ABO = 90°$.



(c) Right-angled triangle PQR is inscribed in the parabola with equation $y = x^2$, as shown. Points P, Q and R have coordinates (p, p^2), (q, q^2) and (r, r^2), respectively. If p, q and r are integers, show that $2q + p + r = 0$.



4. The positive divisors of 21 are 1, 3, 7 and 21. Let $S(n)$ be the sum of the positive divisors of the positive integer n. For example, $S(21) = 1 + 3 + 7 + 21 = 32$.

(a) If p is an odd prime integer, find the value of p such that $S(2p^2) = 2613$.

(b) The consecutive integers 14 and 15 have the property that $S(14) = S(15)$. Determine all pairs of consecutive integers m and n such that $m = 2p$ and $n = 9q$ for prime integers $p, q > 3$, and $S(m) = S(n)$.

(c) Determine the number of pairs of distinct prime integers p and q, each less than 30, with the property that $S(p^3q)$ is not divisible by 24.

2012 Hypatia Contest (English)

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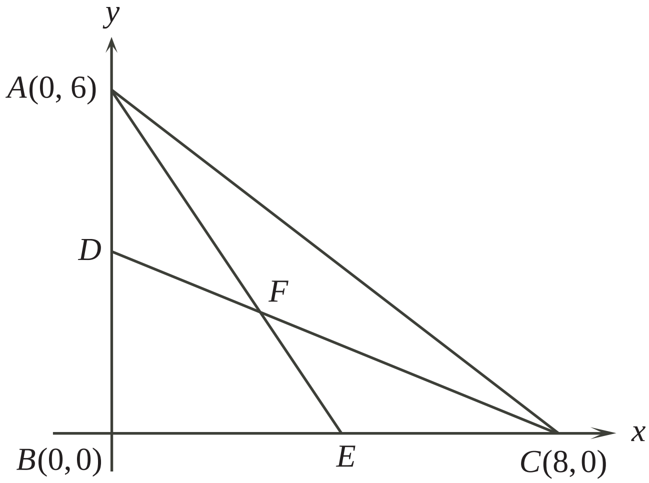
2011 Hypatia Contest (Grade 11)

Wednesday, April 13, 2011

1. In the diagram, D and E are the midpoints of AB and BC respectively.



   (a) Determine an equation of the line passing through the points C and D.
   (b) Determine the coordinates of F, the point of intersection of AE and CD.
   (c) Determine the area of $\triangle DBC$.
   (d) Determine the area of quadrilateral $DBEF$.

2. A set S consists of all two-digit numbers such that:

   - no number contains a digit of 0 or 9, and
   - no number is a multiple of 11.

   (a) Determine how many numbers in S have a 3 as their tens digit.
   (b) Determine how many numbers in S have an 8 as their ones digit.
   (c) Determine how many numbers are in S.
   (d) Determine the sum of all the numbers in S.

3. Positive integers (x, y, z) form a *Trenti-triple* if $3x = 5y = 2z$.

   (a) Determine the values of y and z in the Trenti-triple $(50, y, z)$.
   (b) Show that for every Trenti-triple (x, y, z), y must be divisible by 6.
   (c) Show that for every Trenti-triple (x, y, z), the product xyz must be divisible by 900.

4. Let $F(n)$ represent the number of ways that a positive integer n can be written as the sum of positive odd integers. For example,

- $F(5) = 3$ since

$$\begin{aligned} 5 &= 1+1+1+1+1 \\ &= 1+1+3 \\ &= 5 \end{aligned}$$

- $F(6) = 4$ since

$$\begin{aligned} 6 &= 1+1+1+1+1+1 \\ &= 1+1+1+3 \\ &= 3+3 \\ &= 1+5 \end{aligned}$$

(a) Find $F(8)$ and list all the ways that 8 can be written as the sum of positive odd integers.

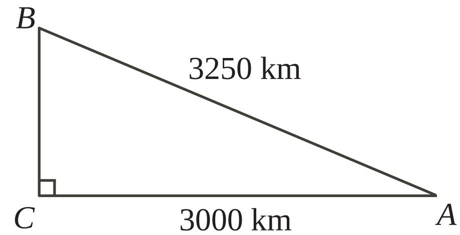
(b) Prove that $F(n+1) > F(n)$ for all integers $n > 3$.

(c) Prove that $F(2n) > 2F(n)$ for all integers $n > 3$.

2010 Hypatia Contest (Grade 11)

Friday, April 9, 2010

1. Piravena must make a trip from A to B, then from B to C, then from C to A. Each of these three parts of the trip is made entirely by bus or entirely by airplane. The cities form a right-angled triangle as shown, with C a distance of 3000 km from A and with B a distance of 3250 km from A. To take a bus, it costs Piravena \$0.15 per kilometre. To take an airplane, it costs her a \$100 booking fee, plus \$0.10 per kilometre.



   (a) To begin her trip she flew from A to B. Determine the cost to fly from A to B.

   (b) Determine the distance she travels for her complete trip.

   (c) Piravena chose the least expensive way to travel between cities and her total cost was \$1012.50. Given that she flew from A to B, determine her method of transportation from B to C and her method of transportation from C to A.

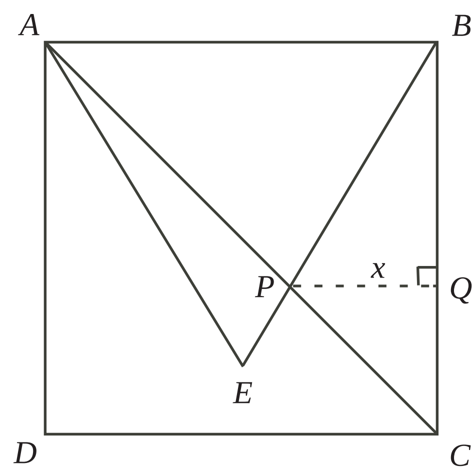
2. A function f is such that $f(x) - f(x-1) = 4x - 9$ and $f(5) = 18$.

   (a) Determine the value of $f(6)$.

   (b) Determine the value of $f(3)$.

   (c) If $f(x) = 2x^2 + px + q$, determine the values of p and q.

3. In the diagram, square $ABCD$ has sides of length 4, and $\triangle ABE$ is equilateral. Line segments BE and AC intersect at P. Point Q is on BC so that PQ is perpendicular to BC and $PQ = x$.



   (a) Determine the measures of the angles of $\triangle BPC$.

   (b) Find an expression for the length of BQ in terms of x.

   (c) Determine the exact value of x.

   (d) Determine the exact area of $\triangle APE$.

4. (a) Determine all real values of x satisfying the equation $x^4 - 6x^2 + 8 = 0$.

   (b) Determine the smallest positive integer N for which $x^4 + 2010x^2 + N$ can be factored as $(x^2 + rx + s)(x^2 + tx + u)$ with r, s, t, u integers and $r \neq 0$.

   (c) Prove that $x^4 + Mx^2 + N$ cannot be factored as in (b) for any integers M and N with $N - M = 37$.

2009 Hypatia Contest (Grade 11)

Wednesday, April 8, 2009

1. Emma counts the number of students in her class with each eye and hair colour, and summarizes the results in the following table:

		Hair Colour		
		Brown	Blonde	Red
Eye Colour	Blue	3	2	1
	Green	2	4	2
	Brown	2	3	1

   (a) What percentage of the students have both green eyes and brown hair?

   (b) What percentage of the students have green eyes or brown hair or both?

   (c) Of the students who have green eyes, what percentage also have red hair?

   (d) Determine how many students with red hair must join the class so that the percentage of the students in the class with red hair becomes 36%.

2. An arithmetic sequence is a sequence in which each term after the first is obtained from the previous term by adding a constant d, called the common difference. For example, the sequence 2, 11, 20, 29, 38 is an arithmetic sequence with five terms and a common difference of $d = 9$.

   (a) An arithmetic sequence has three terms. The three terms add to 180. Determine the middle term of this sequence.

   (b) An arithmetic sequence has five terms. The five terms add to 180. Show that at least one of the five terms equals 36.

   (c) An arithmetic sequence has six terms. The six terms in the sequence add to 180. Determine the sum of the first and sixth terms of the sequence.

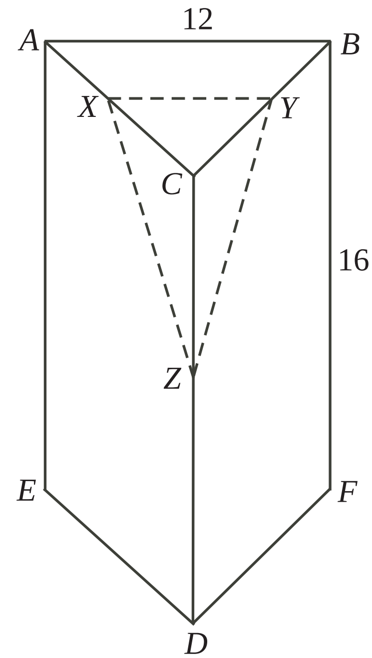
3. Triangle ABC has vertices $A(0, 8)$, $B(2, 0)$, $C(8, 0)$.

   (a) Determine the equation of the line through B that cuts the area of $\triangle ABC$ in half.

   (b) A vertical line intersects AC at R and BC at S, forming $\triangle RSC$. If the area of $\triangle RSC$ is 12.5, determine the coordinates of point R.

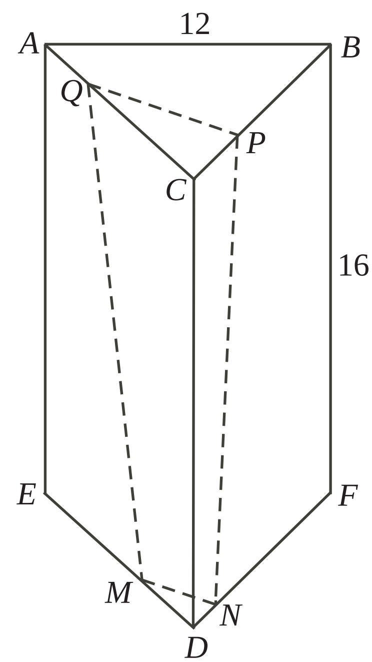
   (c) A horizontal line intersects AB at T and AC at U, forming $\triangle ATU$. If the area of $\triangle ATU$ is 13.5, determine the equation of the horizontal line.

4. (a) A solid right prism $ABCDEF$ has a height of 16, as shown. Also, its bases are equilateral triangles with side length 12. Points X, Y, and Z are the midpoints of edges AC, BC, and DC, respectively. Determine the lengths of XY, YZ and XZ.



(b) A part of the prism above is sliced off with a straight cut through points X, Y and Z. Determine the surface area of solid $CXYZ$, the part that was sliced off.

(c) The prism $ABCDEF$ in part (a) is sliced with a straight cut through points M, N, P, and Q on edges DE, DF, CB, and CA, respectively. If $DM = 4$, $DN = 2$, and $CQ = 8$, determine the volume of the solid $QPCDMN$.



2008 Hypatia Contest (Grade 11)

Wednesday, April 16, 2008

1. For numbers a and b, the notation $a\nabla b$ means $2a + b^2 + ab$.
   For example, $1\nabla 2 = 2(1) + 2^2 + (1)(2) = 8$.

   (a) Determine the value of $3\nabla 2$.

   (b) If $x\nabla(-1) = 8$, determine the value of x.

   (c) If $4\nabla y = 20$, determine the two possible values of y.

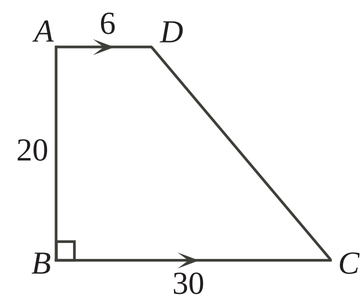
   (d) If $(w-2)\nabla w = 14$, determine all possible values of w.

2. (a) Determine the equation of the line through the points $A(7, 8)$ and $B(9, 0)$.

   (b) Determine the coordinates of P, the point of intersection of the line $y = 2x - 10$ and the line through A and B.

   (c) Is P closer to A or to B? Explain how you obtained your answer.

3. In the diagram, $ABCD$ is a trapezoid with AD parallel to BC and BC perpendicular to AB. Also, $AD = 6$, $AB = 20$, and $BC = 30$.



   (a) Determine the area of trapezoid $ABCD$.

   (b) There is a point K on AB such that the area of $\triangle KBC$ equals the area of quadrilateral $KADC$. Determine the length of BK.

   (c) There is a point M on DC such that the area of $\triangle MBC$ equals the area of quadrilateral $MBAD$. Determine the length of MC.

4. The *peizi-sum* of a sequence $a_1, a_2, a_3, \ldots, a_n$ is formed by adding the products of all of the pairs of distinct terms in the sequence. For example, the peizi-sum of the sequence a_1, a_2, a_3, a_4 is $a_1a_2 + a_1a_3 + a_1a_4 + a_2a_3 + a_2a_4 + a_3a_4$.

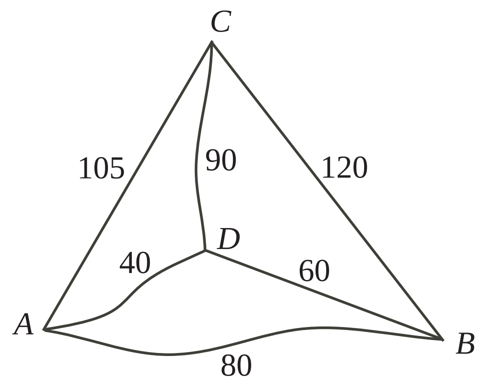
   (a) The peizi-sum of the sequence $2, 3, x, 2x$ is -7. Determine the possible values of x.

   (b) A sequence has 100 terms. Of these terms, m are equal to 1 and n are equal to -1. The rest of the terms are equal to 2. Determine, in terms of m and n, the number of pairs of distinct terms that have a product of 1.

   (c) A sequence has 100 terms, with each term equal to either 2 or -1. Determine, with justification, the minimum possible peizi-sum of the sequence.

2007 Hypatia Contest (Grade 11)
Wednesday, April 18, 2007

1. The diagram shows four cities A, B, C, and D, with the distances between them in kilometres.



   (a) Penny must travel from A through each of the other cities exactly once and then back to A. An example of her route might be $A \to B \to D \to C \to A$.
   List all routes that Penny could travel.

   (b) Identify one route of the shortest possible length and one of the longest possible length. Explain how you obtained your answer.

   (c) Just before leaving A, Penny learns that
   - she must visit a fifth city E,
   - E is connected directly to each of A, B, C, and D, and
   - E must be the third city she visits.

   Therefore, the trip would be $A \to \_\_\_ \to \_\_\_ \to E \to \_\_\_ \to A$.
   How many different routes are now possible? Explain how you obtained your answer.

   (d) The trip $A \to D \to C \to E \to B \to A$ is 600 km long.
   The trip $A \to C \to D \to E \to B \to A$ is 700 km long.
   The distance from D to E is 225 km.
   What is the distance from C to E? Explain how you obtained your answer.

2. Olayuk has four pails labelled P, Q, R, and S, each containing some marbles. A "legal move" is to take one marble from each of three of the pails and put the marbles into the fourth pail.

   (a) Initially, the pails contain 9, 9, 1, and 5 marbles. Describe a sequence of legal moves that results in 6 marbles in each pail.

   (b) Suppose that the pails initially contain 31, 27, 27, and 7 marbles. After a number of legal moves, each pail contains the same number of marbles.
      i. Describe a sequence of legal moves to obtain the same number of marbles in each pail.
      ii. Explain why at least 8 legal moves are needed to obtain the same number of marbles in each pail.

   (c) Beginning again, the pails contain 10, 8, 11, and 7 marbles. Explain why there is no sequence of legal moves that results in an equal number of marbles in each pail.

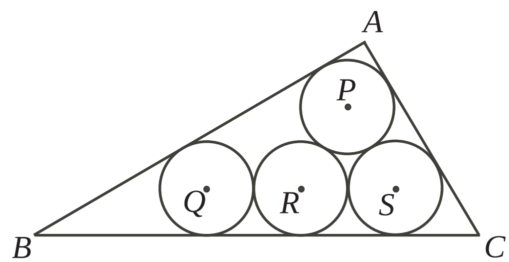
3. Consider the quadratic function $f(x) = x^2 - 4x - 21$.

   (a) Determine all values of x for which $f(x) = 0$ (that is, $x^2 - 4x - 21 = 0$).

   (b) If s and t are different real numbers such that $s^2 - 4s - 21 = t^2 - 4t - 21$ (that is, $f(s) = f(t)$), determine the possible values of $s + t$. Explain how you obtained your answer.

   (c) If a and b are different positive integers such that $(a^2 - 4a - 21) - (b^2 - 4b - 21) = 4$, determine all possible values of a and b. Explain how you obtained your answer.

4. In the diagram, four circles of radius 1 with centres P, Q, R, and S are tangent to one another and to the sides of $\triangle ABC$, as shown.



   (a) Determine the size of each of the angles of $\triangle PQS$. Explain how you obtained your answer.

   (b) Determine the length of each side of $\triangle ABC$. Explain how you obtained your answer.

   (c) The radius of the circle with centre R is decreased so that

   - the circle with centre R remains tangent to BC,
   - the circle with centre R remains tangent to the other three circles, and
   - the circle with centre P becomes tangent to the other three circles.

   This changes the size and shape of $\triangle ABC$. Determine r, the new radius of the circle with centre R.

2006 Hypatia Contest (Grade 11)

Thursday, April 20, 2006

1. The odd positive integers are arranged in rows in the triangular pattern, as shown.

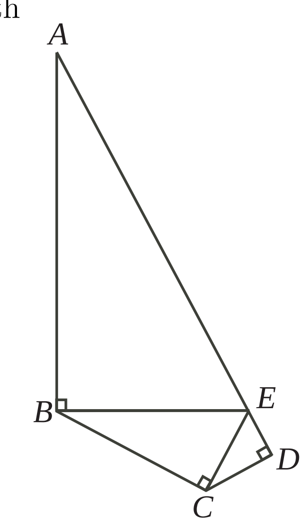
$$\begin{array}{ccccccccc} & & & & 1 & & & & \\ & & & 3 & & 5 & & & \\ & & 7 & & 9 & & 11 & & \\ & 13 & & 15 & & 17 & & 19 & \\ 21 & & 23 & & \cdots & & & & \end{array}$$

   (a) What is the 25th odd positive integer? In which row of the pattern will this integer appear?

   (b) What is the 19th integer that appears in the 21st row? Explain how you got your answer.

   (c) Determine the row and the position in that row where the number 1001 occurs. Explain how you got your answer.

2. In the diagram, $\triangle ABE$, $\triangle BCE$ and $\triangle CDE$ are right-angled, with $\angle AEB = \angle BEC = \angle CED = 60^\circ$, and $AE = 24$.



   (a) Determine the length of CE.

   (b) Determine the perimeter of quadrilateral $ABCD$.

   (c) Determine the area of quadrilateral $ABCD$.

3. A line ℓ passes through the points $B(7, -1)$ and $C(-1, 7)$.

   (a) Determine the equation of this line.

   (b) Determine the coordinates of the point P on the line ℓ so that P is equidistant from the points $A(10, -10)$ and $O(0, 0)$ (that is, so that $PA = PO$).

   (c) Determine the coordinates of all points Q on the line ℓ so that $\angle OQA = 90^\circ$.

4. The abundancy index $I(n)$ of a positive integer n is $I(n) = \dfrac{\sigma(n)}{n}$, where $\sigma(n)$ is the sum of all of the positive divisors of n, including 1 and n itself.

   For example, $I(12) = \dfrac{1+2+3+4+6+12}{12} = \dfrac{7}{3}$.

   (a) Prove that $I(p) \leq \frac{3}{2}$ for every prime number p.

   (b) For every odd prime number p and for all positive integers k, prove that $I(p^k) < 2$.

   (c) If p and q are different prime numbers, determine $I(p^2)$, $I(q)$ and $I(p^2q)$, and prove that $I(p^2)I(q) = I(p^2q)$.

   (d) Determine, with justification, the smallest odd positive integer n such that $I(n) > 2$.

2005 Hypatia Contest (Grade 11)
Wednesday, April 20, 2005

1. For numbers a and b, the notation $a \diamond b$ means $a^2 - 4b$. For example, $5 \diamond 3 = 5^2 - 4(3) = 13$.

   (a) Evaluate $2 \diamond 3$.

   (b) Find all values of k such that $k \diamond 2 = 2 \diamond k$.

   (c) The numbers x and y are such that $3 \diamond x = y$ and $2 \diamond y = 8x$.
   Determine the values of x and y.

2. Gwen and Chris are playing a game. They begin with a pile of toothpicks, and use the following rules:

   - The two players alternate turns
   - On any turn, the player can remove 1, 2, 3, 4, or 5 toothpicks from the pile
   - The same number of toothpicks cannot be removed on two different turns
   - The last person who is able to play wins, regardless of whether there are any toothpicks remaining in the pile

   For example, if the game begins with 8 toothpicks, the following moves could occur:

   Gwen removes 1 toothpick, leaving 7 in the pile
   Chris removes 4 toothpicks, leaving 3 in the pile
   Gwen removes 2 toothpicks, leaving 1 in the pile

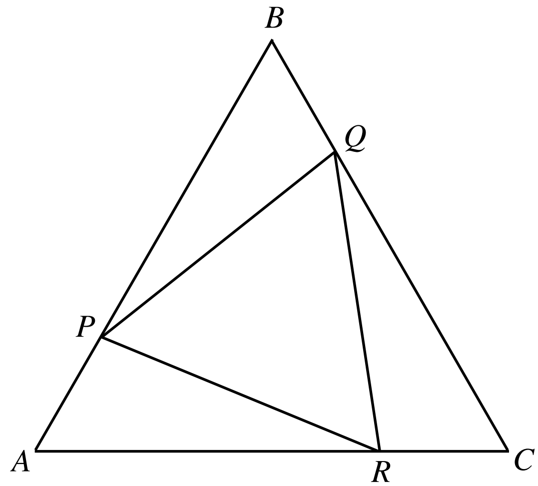
   Gwen is now the winner, since Chris cannot remove 1 toothpick. (Gwen already removed 1 toothpick on one of her turns, and the third rule says that 1 toothpick cannot be removed on another turn.)

   (a) Suppose the game begins with 11 toothpicks. Gwen begins by removing 3 toothpicks. Chris follows and removes 1. Then Gwen removes 4 toothpicks. Explain how Chris can win the game.

   (b) Suppose the game begins with 10 toothpicks. Gwen begins by removing 5 toothpicks. Explain why Gwen can always win, regardless of what Chris removes on his turn.

   (c) Suppose the game begins with 9 toothpicks. Gwen begins by removing 2 toothpicks. Explain how Gwen can always win, regardless of how Chris plays.

3. In the diagram, $\triangle ABC$ is equilateral with side length 4. Points P, Q and R are chosen on sides AB, BC and CA, respectively, such that $AP = BQ = CR = 1$.



   (a) Determine the exact area of $\triangle ABC$. Explain how you got your answer.

   (b) Determine the exact areas of $\triangle PBQ$ and $\triangle PQR$. Explain how you got your answers.

4. An *arrangement* of a set is an ordering of all of the numbers in the set, in which each number appears exactly once. For example, 312 and 231 are two of the possible arrangements of $\{1, 2, 3\}$.

   (a) Determine the number of triples (a, b, c) where a, b and c are three different numbers chosen from $\{1, 2, 3, 4, 5\}$ with $a < b$ and $b > c$. Explain how you got your answer.

   (b) How many arrangements of $\{1, 2, 3, 4, 5, 6\}$ contain the digits 254 consecutively in that order? Explain how you got your answer.

   (c) A *local peak* in an arrangement occurs where there is a sequence of 3 numbers in the arrangement for which the middle number is greater than both of its neighbours.
   For example, the arrangement 35241 of $\{1, 2, 3, 4, 5\}$ contains 2 local peaks.
   Determine, with justification, the average number of local peaks in all 40 320 possible arrangements of $\{1, 2, 3, 4, 5, 6, 7, 8\}$.

2004 Hypatia Contest (*Grade 11*)

Thursday, April 15, 2004

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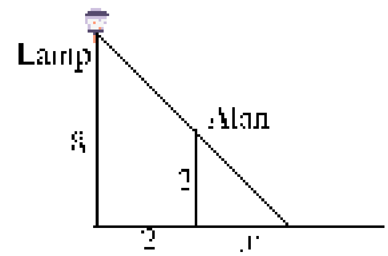
1. (a) Find all values of x which are roots of the equation $x^2 + 5x + 6 = 0$.

   (b) The roots of $x^2 + 5x + 6 = 0$ are each increased by 7. Find a quadratic equation that has these new numbers as roots.

   (c) The roots of $(x-4)(3x^2 - x - 2) = 0$ are each increased by 1. Find an equation that has these new numbers as roots.

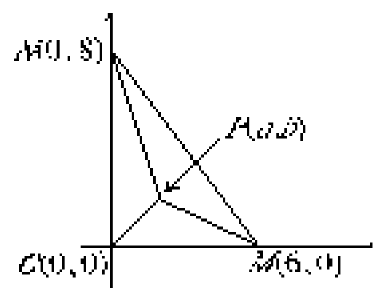
2. Two basketball players, Alan and Bobbie, are standing on level ground near a lamp-post which is 8 m tall. Each of the two players casts a shadow on the ground.

   (a) In the diagram, Alan is standing 2 m from the lamp-post. If Alan is 2 m tall, determine the value of x, the length of his shadow.

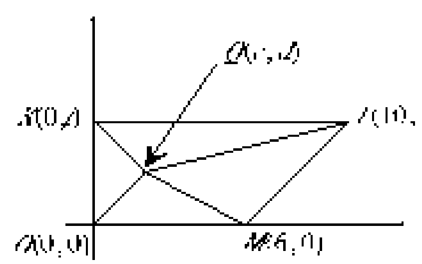


   (b) Bobbie is 1.5 m tall and is standing on the opposite side of the lamp-post from Alan. How far from the lamp-post should she stand so that she casts a shadow of length 3 m?

3. (a) In the diagram, triangle OMN has vertices $O(0,0)$, $M(6,0)$ and $N(0,8)$. Determine the coordinates of point $P(a,b)$ inside the triangle so that the areas of the triangles POM, PON and PMN are all equal.



   (b) In the diagram, quadrilateral $OMLK$ has vertices $O(0,0)$, $M(6,0)$, $L(10,t)$, and $K(0,t)$, where $t > 0$. Show that there is no point $Q(c,d)$ inside the quadrilateral so that the areas of the triangles QOM, QML, QLK, and QKO are all equal.



4. (a) 1 green, 1 yellow and 2 red balls are placed in a bag. Two balls of *different* colours are selected at random. These two balls are then removed and replaced with one ball of the *third* colour. (Enough extra balls of each colour are kept to the side for this purpose.) This process continues until there is only one ball left in the bag, or all of the balls are the same colour. What is the colour of the ball or balls that remain at the end?

   (b) 3 green, 4 yellow and 5 red balls are placed in a bag. If a procedure identical to that in part (a) is carried out, what is the colour of the ball or balls that remain at the end?

   (c) 3 green, 4 yellow and 5 red balls are placed in a bag. This time, two balls of different colours are selected at random, removed, and replaced with *two* balls of the third colour. Show that it is impossible for all of the remaining balls to be the same colour, no matter how many times this process is repeated.

2003 Hypatia Contest *(Grade 11)*

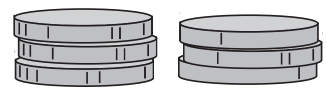
Wednesday, April 16, 2003

1. (a) Quentin has a number of square tiles, each measuring 1 cm by 1 cm. He tries to put these small square tiles together to form a larger square of side length n cm, but finds that he has 92 tiles left over. If he had increased the side length of the larger square to $(n+2)$ cm, he would have been 100 tiles short of completing the larger square. How many tiles does Quentin have?

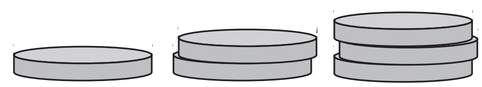
   (b) Quentin's friend Rufus arrives with a big pile of identical blocks, each in the shape of a cube. Quentin takes some of the blocks and Rufus takes the rest. Quentin uses his blocks to try to make a large cube with 8 blocks along each edge, but finds that he is 24 blocks short. Rufus, on the other hand, manages to exactly make a large cube using all of his blocks. If they use all of their blocks together, they are able to make a complete cube which has a side length that is 2 blocks longer than Rufus' cube. How many blocks are there in total?

2. Xavier and Yolanda are playing a game starting with some coins arranged in piles. Xavier always goes first, and the two players take turns removing one or more coins from any *one* pile. The player who takes the last coin wins.

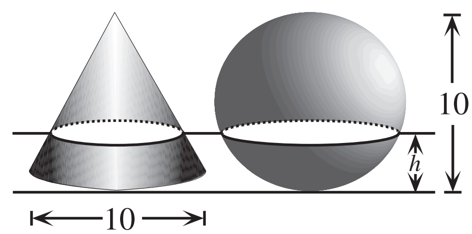
   (a) If there are two piles of coins with 3 coins in each pile, show that Yolanda can guarantee that she always wins the game.



   (b) If the game starts with piles of 1, 2 and 3 coins, explain how Yolanda can guarantee that she always wins the game.

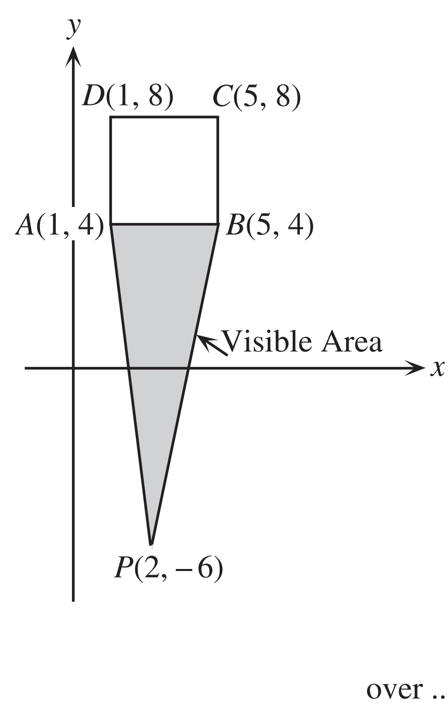


3. In the diagram, the sphere has a diameter of 10 cm. Also, the right circular cone has a height of 10 cm, and its base has a diameter of 10 cm. The sphere and cone sit on a horizontal surface. If a horizontal plane cuts both the sphere and the cone, the cross-sections will both be circles, as shown. Find the height of the horizontal plane that gives circular cross-sections of the sphere and cone of equal area.

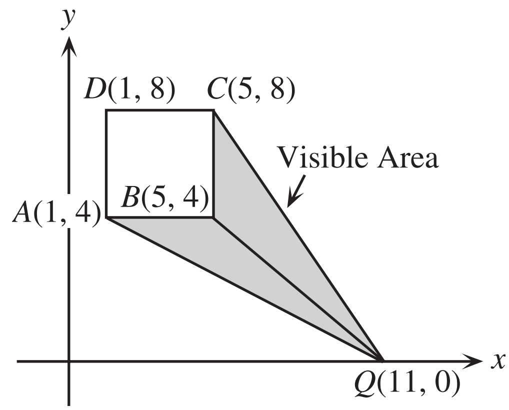


4. Square $ABCD$ has vertices $A(1,4)$, $B(5,4)$, $C(5,8)$, and $D(1,8)$. From a point P outside the square, a vertex of the square is said to be *visible* if it can be connected to P by a straight line that does not pass through the square. Thus, from any point P outside the square, either two or three of the vertices of the square are visible. The *visible area of P* is the area of the one triangle or the sum of the areas of the two triangles formed by joining P to the two or three visible vertices of the square.

   (a) Show that the *visible area* of $P(2,-6)$ is 20 square units.



(b) Show that the visible area of $Q(11, 0)$ is also 20 square units.



(c) The set of points P for which the visible area equals 20 square units is called the *20/20 set*, and is a polygon. Determine the perimeter of the 20/20 set.

Extensions (Attempt these only when you have completed as much as possible of the four main problems.)

Extension to Problem 1:
As in Question 1(a), Quentin tries to make a large square out of square tiles and has 92 tiles left over. In an attempt to make a second square, he increases the side length of this first square by *an unknown number of tiles* and finds that he is 100 tiles short of completing the square. How many different numbers of tiles is it possible for Quentin to have?

Extension to Problem 2:
If the game starts with piles of 2, 4 and 5 coins, which player wins if both players always make their best possible move? Explain the winning strategy.

Extension to Problem *3*:
A sphere of diameter d and a right circular cone with a base of diameter d stand on a horizontal surface. In this case, the height of the cone is equal to the *radius* of the sphere. Show that, for any horizontal plane that cuts both the cone and the sphere, the *sum* of the areas of the circular cross-sections is always the same.

Extension to Problem 4:
From any point P outside a unit cube, 4, 6 or 7 vertices are visible in the same sense as in the case of the square. Connecting point P to each of these vertices gives 1, 2 or 3 square-based pyramids, which make up the *visible volume* of P. The *20/20 set* is the set of all points P for which the visible volume is 20, and is a polyhedron. What is the surface area of this 20/20 set?