Appendix I

The "Elusive Formulas" - Part 1

This packet from the Mathematical Association of America includes mathematics that an excellent high school student would know. Mathematics that an ERA student completing Algebra 2 should know are marked with a box (☐). (ERA students should know other mathematics too, such as matrices.)

Geometry

a, b, c, s = sides
b_1, b_2 = bases
h = height

l = length
A = area
R, r = radii

C = circumference
V = volume
P = perimeter

Triangle
☐ Sum of angles = 180°
☐ P = a + b + c
☐ A = (1/2)b_1 h

Right Triangle
☐ $P = b + h + \sqrt{(b^2 + h^2)}$
☐ A = (b_1 h/2)
45° - 45° - 90°
☐ H = L√2
30° – 60° – 90°
☐ L opposite 30° = (1/2)(H)
☐ L opposite 60° = (√(3)/2)(H)

Equilateral Triangle
☐ P = 3s
☐ $A = s^2 \sqrt{(3)}/4.$
☐ $A = h^2 \sqrt{(3)}/3$

Pythagorean Theorem
☐ $a^2 + b^2 = c^2$

☐ Pythagorean Triples: 3,4, 5; 5,12, 13; 8, 15, 17

Heron's Formula
☐ A = √(s(s – a)(s – b)(s – c))
☐ S = semi perimeter = (a + b + c)/2

Square
☐ P = 4s
☐ $A = s^2$
Rectangle (see next column)
☐ P = 2(l + w)
☐ A = lw

Parallelogram
☐ P = 2(l + w)
☐ A = b_1 h

Trapezoid
☐ P=a + b + c + d
☐ A = (h/2)(b_1 + b_2)

Circle
☐ Number of degrees = 360°
☐ Number of radians = 2π
☐ $A = \pi r^2$
☐ C = 2πr

Theta, θ, is in radians
☐ Arc of a circle = r θ
☐ Segment of a circle = r^2 [θ - sin (θ)]/2
☐ Sector of a circle = $r^2\theta/2$

Radians to Degrees
☐ Multiply radians by 180/π

Degrees to Radians
☐ Multiply degrees by π/180

Ellipse
A = Rrπ

Solids

Angles
(Answers will be in degrees unless otherwise noted)

☐ Sum of Interior Angles: 180(n-2)
☐ Sum of Exterior Angles: 360
☐ Each Interior Angle (regular poly): 180(n-2)/n
☐ Each Exterior Angle (regular poly): 360/n
☐ Sum of angles of triangle: 180
☐ Measure of exterior angle of triangle: the sum of the two non-adjacent interior angles.
☐ The sum of any two sides of a triangle is greater than the third side
☐ To convert a degree measure to radians multiply by π/180
☐ To convert a radian measure to degrees multiply by 180/π
☐ Complementary angles are two angles whose sum is 90
☐ Supplementary angles are two angles whose sum is 180.

Slope Formula:
m, m_1, m_2 = slopes
☐ $m = (y_1 - y_2)/(x_1 - x_2)$ = rise/run

Slope-Intercept Method:
☐ $Y = mx + b$
☐ b = y-intercept

Point-Slope Method:
☐ $y - y_1 = m(x - x_1)$
☐ (x_1, y_1) is a point on the line

Standard Form:
☐ $Ax + By = C$
where A and B are not both zero

☐ Distance Formula:
$d = ((x_1 - x_2)^2 + (y_1 - y_2)^2)^{(1/2)}$

Midpoint Formula:
☐ $(x, y) = ((x_1 + x_2)/2, (y_1 + y_2)/2)$

☐ Parallel lines: $m_1 = m_2$
☐ Perpendicular lines: $m_1 m_2 = -1$

☐ d = rt; distance = rate x time

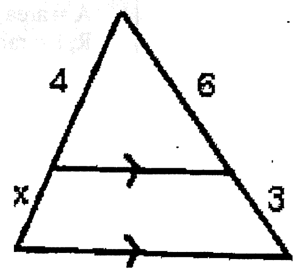
i = prt; interest = principal x interest rate x time

Equations of Circles and Parabolas
Circle, center at origin:
☐ $x^2 + y^2 = r^2$

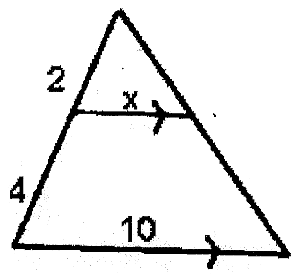
Circle, center at (h,k):
☐ $(x-h)^2 + (y-k)^2 = r^2$

Parabola:
☐ $y = ax^2 + bx + c$

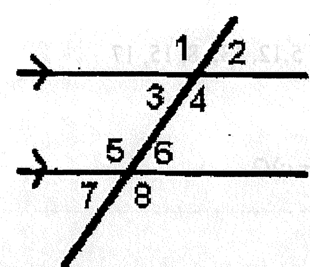
☐ Two triangles are similar if the corresponding angles are congruent and the corresponding sides are in proportion.



$$\frac{4}{(4+x)} = \frac{6}{9}$$
$$36 = 24 + 6x$$
$$12 = 6x$$
$$2 = x$$



$$\frac{x}{10} = \frac{2}{6}$$
$$6x = 20$$
$$x = \frac{20}{6}$$
$$x = \frac{10}{3}$$



☐ Corresponding angles are equal. \1=\5, \2=\6, \3=\7, \4=\8
☐ Alternate Interior angles are equal. \3=\6, \4=\5
☐ Alternate Exterior angles are equal. \1=\8, \2=\7
☐ Same side interior angles are supplementary. \3+\5=180, \4+\6=180

- $\sin\theta = \dfrac{opposite}{hypotenuse}$
- $\cos\theta = \dfrac{adjacent}{hypotenuse}$
- $\tan\theta = \dfrac{opposite}{adjacent} = \dfrac{\sin\theta}{\cos\theta}$
- $\csc\theta = \dfrac{1}{\sin\theta}$
- $\sec\theta = \dfrac{1}{\cos\theta}$
- $\cot\theta = \dfrac{1}{\tan\theta} = \dfrac{\cos\theta}{\sin\theta}$
- Law of Sines

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

- Law of Cosines

$$a^2 = b^2 + c^2 - 2bc\cos A$$
$$b^2 = a^2 + c^2 - 2ac\cos B$$
$$c^2 = a^2 + b^2 - 2ab\cos C$$

$$\sin(A \pm B) = \sin A\cos B \pm \cos A\sin B$$
$$\cos(A \pm B) = \cos A\cos B \mp \sin A\sin B$$
$$\tan(A \pm B) = \frac{\tan A \pm \tan B}{1 \mp \tan A\tan B}$$

$$= 2\cos^2\theta - 1 = 1 - 2\sin^2\theta$$
$$\tan 2\theta = \frac{2\tan\theta}{1-\tan^2\theta}$$
$$\sin\left(\frac{\theta}{2}\right) = \sqrt{\frac{1-\cos\theta}{2}}$$
$$\cos\left(\frac{\theta}{2}\right) = \sqrt{\frac{1+\cos\theta}{2}}$$
$$\tan\left(\frac{\theta}{2}\right) = \frac{1-\cos\theta}{\sin\theta} = \frac{\sin\theta}{1+\cos\theta}$$
$$\sin^2\theta + \cos^2\theta = 1$$
$$1 + \tan^2\theta = \sec^2\theta$$
$$1 + \cot^2\theta = \csc^2\theta$$
$$\sin(-\theta) = -\sin\theta$$
$$\cos(-\theta) = \cos\theta$$
$$\tan(-\theta) = -\tan\theta$$
$$\cos\left(\frac{\pi}{2} - \theta\right) = \sin\theta$$

$$\sin\left(\frac{\pi}{2} - \theta\right) = \cos\theta$$
$$\sin A \cdot \sin B = \frac{1}{2}\left[-\cos(A+B) + \cos(A-B)\right]$$
$$\cos A \cdot \cos B = \frac{1}{2}\left[\cos(A+B) + \cos(A-B)\right]$$
$$\sin A \cdot \cos B = \frac{1}{2}\left[\sin(A+B) + \sin(A-B)\right]$$

$$\sin\left(\frac{\pi}{2} - \theta\right) = \cos\theta$$
$$\cos\left(\frac{\pi}{2} - \theta\right) = \sin\theta$$

$y = \sin^{-1} x = \arcsin x$

$D: -1 \le x \le 1$

$R: -\frac{\pi}{2} \le y \le \frac{\pi}{2}$

$y = \cos^{-1} x = \arccos x$

$D: -1 \le x \le 1$

$R: 0 \le y \le \pi$

□ unit circle
amplitude
period
phase shift
vertical shift
graphs of 6 basics

□ Complex Numbers Know how to add (subtract), multiply (divide), rationalize the denominator, find absolute value (magnitude): $(a+bi)+(c+di) = (a+c)+(b+d)i$

$a + bi = re^{i\theta}$

$(a+bi)(c+di) = (ac-bd)+(ad+bc)i$

$r = \sqrt{a^2+b^2}$ and $\tan\theta = \frac{b}{a}$ $|a+bi| = \sqrt{a^2+b^2}$

Area of Triangle

□ $K = \frac{1}{2}ab\sin C$

Conics

General Form

$Ax^2 + Cy^2 + Dx + Ey + F = 0$

where A, C, D, E, F ∈ I

Standard Form

$(x - h)^2 + (y - k)^2 = y^2$

$\frac{(x-h)^2}{a^2} + \frac{(y-k)^2}{b^2} = 1$

$\frac{(x-h)^2}{a^2} - \frac{(y-k)^2}{b^2} = \pm 1$

$y - k = a(x-h)^2$

$x - h = a(y-k)^2$

Appendix I - The "Elusive Formulas" continued

Distance
- 1 foot = 12 inches
- 1 yard = 3 feet
- 1 mile = 5,280 feet
- 1 mile ≈ 1.61 kilometers
- 1 inch = 2.54 centimeters
- 1 foot = 0.3048 meters
- 1 meter = 1,000 millimeters
- 1 meter = 100 centimeters
- 1 kilometer = 1,000 meters
- 1 kilometer ≈ 0.62 miles

Area
- 1 square foot = 144 square inches
- 1 square yard = 9 square feet
- 1 acre = 43,560 square feet

Volume
- 1 cup = 8 fluid ounces
- 1 quart = 4 cups
- 1 gallon = 4 quarts
- 1 gallon = 231 cubic inches
- 1 liter ≈ 0.264 gallons
- 1 cubic foot = 1,728 cubic inches
- 1 cubic yard = 27 cubic feet
- 1 board foot = 1 inch by 12 inches by 12 inches

Weight
- 1 ounce ≈ 28.350 grams
- 1 pound = 16 ounces
- 1 pound ≈ 453.592 grams
- 1 milligram = 0.001 grams
- 1 kilogram = 1,000 grams
- 1 kilogram ≈ 2.2 pounds
- 1 ton = 2,000 pounds

Electricity
- 1 kilowatt-hour = 1,000 watt-hours
- amps = watts ÷ volts

Temperature
- $°C = (5/9)(°F - 32)$
- $°F = (°C)(9/5) + 32$

Definitions

- *Multiplication Principle.*
  If one of K objects must be chosen and 1 of M other objects must be chosen and 1 of N other objects must be chosen then there are KMN ways to do this.
- *Permutations*
  A permutation is an arrangement of a number of objects in all possible ways. Order counts and without replacement. The formula for the number of permutations of n things taken r at a time:

$$_nP_r=\frac{n!}{(n-r)!}$$

- *Permutations Of Objects Not All Different*
  Given n objects of which r are identical and s are identical and t are identical, the number of permutations is

$$\frac{n!}{r!s!t!}$$

- *Combinations*
  A combination is similar to a permutation, except that order does not count (and still no replacement). The formula for the number of combinations of n things taken r at a time is:

$$_nC_r=\frac{n!}{(n-r)!r!}$$

- *Arrangements With Replacement*
  The number of arrangements with replacement of n things taken r at a time is n^r.
- *Fundamental Rule of Probability.*
  If there are n equally likely outcomes in a sample space, and event E consists of k outcomes, then the probability of E is: P(E)=k/n.
- *Independent Events.*
  "Independent" means the outcome of one event does not affect the outcome of the other. If A and B are independent: $P(A \text{ and } B)=P(A)*P(B)$
- *Dependent Events; Conditional Probability*
  If two events A and B are not independent, then the probability of A and then B involves the conditional probability of B given that A has happened:
  $P(A \text{ and } B)=P(A)*P(B|A)$
- *Mutually Exclusive Events.*
  "Mutually exclusive" means the two events cannot both happen. If A and B are mutually exclusive:
  $P(A \text{ or } B)=P(A)+P(B)$
- *Complementary Events*
  A and (not A) are complementary events. The sum of their probabilities is 1.
  $P(A)+P(\text{not } A)=1$. Equivalently:
  $P(A)=1-P(\text{not } A)$.

Expected Value
Assume an experiment has n mutually exclusive events (E_1, E_2, ..., E_n) with probabilities ($P(E_1)$, $P(E_2)$, ..., $P(E_n)$), and assume the probabilities add up to 1 (that is, there are no other possible events). If each event has a numeric value associated with it, called the payoff, ($Pay(E_1)$, $Pay(E_2)$, ..., $Pay(E_n)$), then the expected value of the experiment is:

$$EV=\sum_{i=1}^{n} P(E_i)*Pay(E_i)= P$$

Expected value is a weighted average of the values associated with each event, where the weights are the probabilities.

- *Binomial Probability*
  If an experiment can have only two outcomes (like flipping a coin), and one outcome (called "success") has probability p and the other outcome (called "failure") has probability q = 1-p, then the probability of k successes in n trials is:

$$P(k,n,p)={}_nC_k\, p^k q^{n-k}$$

Note that if p = q = 1/2, then

$$P(n,k,p)={}_nC_k\, p^k q^{n-k}={}_nC_k\left(\frac{1}{2}\right)^k\left(\frac{1}{2}\right)^{n-k}={}_nC_k\left(\frac{1}{2}\right)^n=\frac{_nC_k}{2^n}$$

Also note that

$$\sum_{k=0}^{n} {}_nC_k=2^n$$

http://www.math.com/tables/

Appendix

II: The "Elusive Formulas" - Part 2

The "Elusive Formulas"[2]

2nd Edition: finalized August 1, 2001
Original Edition: finalized May 23, 2001

Section A – Symbol Table

$\forall$	for all
$\exists$	there exists
$\varnothing$	the empty set
$\in$	is an element of
$\notin$	is not an element of
$\mathbb{N}$, +	the set of natural numbers
$\mathbb{Z}$	the set of integers
$\mathbb{Q}$	the set of rational numbers
$\mathbb{R}$	the set of real numbers
$\mathbb{C}$	the set of complex numbers
$\subseteq$	is a subset of
$\vee$	or
$\wedge$	and
$\cap$	union
$\cup$	intersection
$\Rightarrow$	implies
$\Leftrightarrow$, iff	is equivalent to
$\sum_{i=1}^{n} a_i$	$a_1+a_2+a_3+a_4+a_5+\ldots+a_n$
$\prod_{i=1}^{n} a_i$	$a_1 \cdot a_2 \cdot a_3 \cdot a_4 \cdot a_5 \cdot \ldots \cdot a_n$
$(a,b) = d$	d is the gcd of a and b
$[a,b] = d$	d is the lcm of a and b

$\tau(a)$	number of factors of a
$\sigma(a)$	sum of the factors of a
$\varphi(a)$	Euler Phi Function
$\mu(a)$	Mobius Function
$\lvert a \rvert$	absolute value of a
$\lfloor a \rfloor$	greatest integer function
$\lceil a \rceil$	least integer function
a:b:c	ratio of a to b to c
a:b:c::d:e:f	ratio of a to b to c=ratio of d to e to f
π	pi $\approx 3.141592653589793\ldots$
e	euler number $\approx 2.718281828459\ldots$
$\log_b(a)=c$	$b^c = a$
$\log(a)=c$	$10^c = a$
$n!$	$n(n-1)(n-2)(n-3)(n-4)\ldots 3\times 2\times 1$
${}_nP_r$	$\frac{n!}{r!} = n(n-1)(n-2)\ldots(n-r+1)$
${}_nC_r$ or $\binom{n}{r}$	$\frac{n!}{r!(n-r)!} = \frac{n(n-1)(n-2)\ldots(n-r+1)}{n(n-1)(n-2)\ldots(2)(1)}$

$a \equiv b \pmod{c}$ a and b leave the same remainder when divided by c.

The "Elusive Formulas" pages are used with permission.

Section B – Algebra

- $(a \pm b)^3 = a^3 \pm b^3$ iff a = 0 or b = 0 or (a±b) = 0
- $a^3 \pm b^3 = (a \pm b)(a^2 \mp ab + b^2)$
- $a^3 + b^3 + c^3 - 3abc = (a + b + c)(a^2 + b^2 + c^2 - ab - bc - ca)$
- $a^4 + b^4 + c^4 - 2a^2b^2 - 2b^2c^2 - 2c^2a^2 = -16s(s - a)(s - b)(s - c)$ when 2s = a+b+c
- $a^n + b^n = (a + b)(a^{n-1} + b^{n-1}) - ab(a^{n-2} + b^{n-2})$
- $a^n \pm b^n = (a \pm b)(a^{n-1} \mp a^{n-2}b + a^{n-3}b^2 \mp a^{n-4}b^3 + \ldots + a^2b^{n-3} \mp ab^{n-2} + b^{n-1})$ [$a^n + b^n$ is only true for odd n.]
- $(a \pm b)^n = {}_nC_0a^n \pm {}_nC_1a^{n-1}b + {}_nC_2a^{n-2}b^2 \pm {}_nC_3a^{n-3}b^3 + {}_nC_4a^{n-4}b^4 \pm \ldots \pm {}_nC_{n-2}a^2b^{n-2} + {}_nC_{n-1}ab^{n-1} + {}_nC_nb^n$
- $a(a+1)(a+2)(a+3) = (a^2+3a+1)^2 - 1$

Arithmetic Series: If $a_1, a_2, a_3, \ldots, a_n$ are in arithmetic series with common difference d:	
n^{th} term in terms of m^{th} term	$a_n = a_m + (n - m)d$
Sum of an arithmetic series up to term n	$\sum_{i=1}^{n} a_i = \frac{n(a_1 + a_n)}{2} = \frac{n(2a_1 + (n-1)d)}{2}$
Geometric Series: If $a_1, a_2, a_3, \ldots, a_n$ are in geometric series with common ratio r:	
n^{th} term of a geometric series	$a_n = a_1r^{n-1}$
Sum of a non-constant ($r \neq 1$) geometric series up to term n	$\sum_{i=1}^{n} a_i = \frac{a_1(1-r^n)}{1-r}$
Sum of an infinite geometric series	$\sum_{i=1}^{\infty} a_i = \frac{a_1}{1-r}$ iff $\lvert r \rvert < 1$

$\sum_{i=1}^{n} i = \frac{n(n+1)}{2}$	$\sum_{i=1}^{n} i^2 = \frac{n(n+1)(2n+1)}{6}$	$\sum_{i=1}^{n} i^3 = \frac{n^2(n+1)^2}{4}$	$\sum_{i=1}^{n} i^4 = \frac{n(n+1)(6n^3+9n^2+n-1)}{30}$

If $P(x) = a_nx^n + a_{n-1}x^{n-1} + a_{n-2}x^{n-2} + a_{n-3}x^{n-3} + \ldots + a_1x + a_0 = 0$, a_i is a constant, then	
Sum of roots taken one at a time (the sum of the roots)	$\sum r_i = \frac{-a_{n-1}}{a_n}$
Sum of roots taken two at a time	$\sum_{i \neq j} r_ir_j = \frac{a_{n-2}}{a_n}$
Sum of roots taken p at a time	$\sum_{i \neq j \neq \ldots \neq k} r_ir_j \ldots r_k = (-1)^p \frac{a_{n-p}}{a_n}$
Rational Root Theorem	
If $P(x) = a_nx^n + a_{n-1}x^{n-1} + a_{n-2}x^{n-2} + a_{n-3}x^{n-3} + \ldots + a_1x + a_0$ is a polynomial with integer coefficients and b/c is a rational root of the equation P(x) = 0 (where (b, c) =1), then $b \mid a_0$ and $c \mid a_n$.	

- If P(x) is a polynomial with real coefficients and $P(a + bi) = 0$, then $P(a - bi) = 0$.
- If P(x) is a polynomial with rational coefficients and $P(a + b\sqrt{c}) = 0$, then $P(a - b\sqrt{c}) = 0$.

Section C – Number Theory

- Number Theory mainly concerns $\mathbb{N}$ and $\mathbb{Z}$, all variables exist in $\mathbb{N}$ unless stated otherwise

Divisibility: $\forall a,b \in$, $a \neq 0$: $a \mid b \Leftrightarrow \exists k \in$ such that $ak = b$		
$1 \mid a$, $a \mid 0$, $a \mid (\pm a)$	$a \mid b \Rightarrow a \mid bc$	$a \mid b \wedge b \mid c \Rightarrow a \mid c$
$a \mid 1 \Leftrightarrow a = \pm 1$	$a \mid b \wedge a \mid c \Rightarrow a \mid (b \pm c)$	$a \mid bc \wedge (a,b) = 1 \Rightarrow a \mid c$
$a \mid b \wedge b \mid a \Leftrightarrow a = \pm b$	$a \mid b \wedge c \mid d \Rightarrow ab \mid cd$	$a \mid c \wedge b \mid c \wedge (a,b) = 1 \Rightarrow ab \mid c$
Modulo Congruence: $\forall a,b,m \in$, $m \neq 0$: $a \equiv b \pmod{m} \Leftrightarrow m \mid (a-b)$		
Suppose that $a \equiv b \pmod{m}$, $c \equiv d \pmod{m}$, and p is prime; then:		
$a \pm g \equiv c \pm g \pmod{m}$	$a \pm b \equiv c \pm d \pmod{m}$	$(g,p) = 1 \Rightarrow g^{p-1} \equiv 1 \pmod{p}$
$ag \equiv cg \pmod{m}$	$ab \equiv cd \pmod{m}$	$(p-1)! \equiv -1 \pmod{p}$
$(g,m) = 1 \Rightarrow g^{\varphi(m)} \equiv 1 \pmod{m}$	$hf \equiv hg \pmod{m} \wedge (m,h) = 1 \Rightarrow f \equiv g \pmod{m}$	

Fibonacci Sequence

- Sequence of integers beginning with two 1's and each subsequent term is the sum of the previous 2 terms.
- 1,1,2,3,5,8,13,21,34,55,89,144, ...
- F(1)=F(2)=1, for n≥3, F(n)=F(n-1)+F(n-2)
- Let ψ = Golden Ratio = $\frac{(\sqrt{5}+1)}{2}$, then F(n) = $\frac{\psi^n - (-\psi)^{-n}}{\sqrt{5}}$
- $F(n)\cdot F(n+3) - F(n+1)\cdot F(n+2) = (-1)^n$

Farey Series [F_n]

- Ascending sequence of irreducible fractions between 0 and 1 inclusive whose denominator is ≤n
- $F_3 = \frac{0}{1}, \frac{1}{3}, \frac{1}{2}, \frac{2}{3}, \frac{1}{1}$; $F_7 = \frac{0}{1}, \frac{1}{7}, \frac{1}{6}, \frac{1}{5}, \frac{1}{4}, \frac{2}{7}, \frac{1}{3}, \frac{2}{5}, \frac{3}{7}, \frac{1}{2}, \frac{4}{7}, \frac{3}{5}, \frac{2}{3}, \frac{5}{7}, \frac{3}{4}, \frac{4}{5}, \frac{5}{6}, \frac{6}{7}, \frac{1}{1}$
- if $\frac{a}{b}, \frac{c}{d}$, and $\frac{e}{f}$ are successive terms in F_n, then bc–ad = de–cf = 1 and $\frac{c}{d} = \frac{a+e}{b+f}$

Number Theory Functions

The following number theory functions have the property that if (a,b)=1, then f(a×b)=f(a)×f(b)

Tau Function: Number of factors of n: $\tau(n) = \prod_{i=1}^{m}(1+\alpha_i)$

Sigma Function: Sum of factors of n: $\sigma(n) = \prod_{i=1}^{m}\left(\sum_{j=0}^{\alpha_i}(p_i^{\,j})\right) = \prod_{i=1}^{m}\left(\frac{p_i^{1+\alpha_i}-1}{p_i-1}\right)$

Euler Phi Function: Number of integers between 0 and n that are relatively prime to n

$$\varphi(n) = \prod_{i=1}^{m}\left(p_i^{\alpha_i} - p_i^{\alpha_i-1}\right) = n\prod_{i=1}^{m}\left(1-\frac{1}{p_i}\right)$$

Mobius Function:

$$\mu(n) = \begin{cases} 0 & \text{if n is divisible by any square} \geq 1 \\ \text{otherwise:} & \\ 1 & \text{if n is has an even number of prime factors} \\ -1 & \text{if n is has an odd number of prime factors} \end{cases}$$

Divisibility Rules		
Given integer k expressed in base $n \geq 2$, $k = a_0 + a_1 n + a_2 n^2 + a_3 n^3 + \dots = \sum_{i=0}^{\infty}\left(a_i n^i\right)$, $0 \leq a_i < n$		
Note: $\left(\overline{a_m a_{m-1} \dots a_0}\right)_n = \sum_{i=0}^{\infty}\left(a_i n^i\right)$, secondary subscript omission implies base10: $\overline{a_m a_{m-1} \dots a_0} = \sum_{i=0}^{\infty}\left(10^i a_i\right)$		
	Divisor (d)	**Criterion**
Basic/Specific	3, 9	If $a_0 + a_1 + a_2 + a_3 + a_4 + \dots$ is divisible by 3 or 9
Basic/Specific	11	If $a_0 - a_1 + a_2 - a_3 + a_4 - \dots$ is divisible by 11
Basic/Specific	7, 13	If $\overline{a_2 a_1 a_0} - \overline{a_5 a_4 a_3} + \overline{a_8 a_7 a_6} - \overline{a_{11} a_{10} a_9} + \dots$ is divisible by 7 or 13
Basic/Specific	$2^m, 5^m$	If $\overline{a_{m-1} a_{m-2} a_{m-3} \dots a_0}$ is divisible by 2^m or 5^m
Basic/Specific	7	Truncate rightmost digit and subtract twice the value of said digit from the remaining integer. Repeat this process until divisibility test becomes trivial.
General	$d \mid n^m$	If $\left(\overline{a_{m-1} a_{m-2} a_{m-3} a_{m-4} \dots a_0}\right)_n$ is divisible by d
General	factor of $n^m - 1$	If $\left(\overline{a_{m-1} a_{m-2} \dots a_1 a_0}\right)_n + \left(\overline{a_{2m-1} a_{2m-2} \dots a_{m+1} a_m}\right)_n + \left(\overline{a_{3m-1} a_{3m-2} \dots a_{2m+1} a_{2m}}\right)_n + \dots$ is divisible
General	factor of $n^m + 1$	If $\left(\overline{a_{m-1} a_{m-2} \dots a_1 a_0}\right)_n - \left(\overline{a_{2m-1} a_{2m-2} \dots a_{m+1} a_m}\right)_n + \left(\overline{a_{3m-1} a_{3m-2} \dots a_{2m+1} a_{2m}}\right)_n - \dots$ is divisible
General	$d = xy$, $(x,y) = 1$	$(x \mid k \text{ and } y \mid k) \Leftrightarrow d \mid k$
General	$d \mid kn \pm 1$	Truncate rightmost digit and add $\mp k$ times the value of said digit from the remaining integer. Repeat this process until divisibility test becomes trivial.

Section D – Logarithms

For b an integer > 1, $\log_b(a) = c \Leftrightarrow b^c = a$	$\log_b(b) = 1$	$\log_b(1) = 0$
$\log(a^c) = c\ \log(a)$	$a^{\log_a(b)} = b$	$\log\left(\frac{ab}{c}\right) = \log(a) + \log(b) - \log(c)$
$\log_a(b)\quad \log_b(c) = \log_a(c)$	$\log_a(b)\quad \log_b(a) = 1$	$a^{\log(b)} = b^{\log(a)}$

Section E – Analytic Geometry

Distance between line $ax + by + c = 0$ and point (x_0, y_0) in 2D plane:	Distance between the plane $ax + by + cz + d = 0$ and point (x_0, y_0, z_0) in 3D space:
$\dfrac{\lvert x_0 a + y_0 b + c \rvert}{\sqrt{a^2 + b^2}}$	$\dfrac{\lvert x_0 a + y_0 b + z_0 c + d \rvert}{\sqrt{a^2 + b^2 + c^2}}$

Section F – Inequalities

- $\mathbb{R}^+$: the set of all positive real numbers; $\mathbb{R}^-$: the set of all negative real numbers
- $a^2 + b^2 \geq 2ab$; (YES) $a^2 + b^2 + c^2 \geq ab + bc + ca$; (NO) $3(a^2 + b^2 + c^2 + d^2) \geq 2(ab + bc + cd + da + ac + bd)$ (NO)
- The "quadratic-arithmetic-geometric-harmonic mean inequality:" for $a_i > 0$

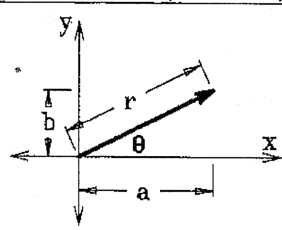
$$\frac{n}{\frac{1}{a_1} + \frac{1}{a_2} + \frac{1}{a_3} + \dots + \frac{1}{a_n}} \leq \sqrt[n]{a_1 a_2 a_3 \dots a_n} \leq \frac{a_1 + a_2 + a_3 + \dots + a_n}{n} \leq \sqrt{\frac{a_1^2 + a_2^2 + a_3^2 + \dots + a_n^2}{n}}$$, with equalities holding iff $a_1 = a_2 = a_3 = a_4 = \dots = a_n$.

- If constant $k > 1$ and large x: $1 < k^{1/x} < x^{1/x} < \log(x) < x^{1/k} < x < x\log(x) < x^k < x^{\log(x)} < k^x < x! < x^x$

- Cauchy-Schwarz Inequality- For 2nd degree: $(a_1b_1+a_2b_2)^2 \le (a_1^2+a_2^2)(b_1^2+b_2^2)$ with equality holding iff $a_1:a_2::b_1:b_2$. In general, for any 2 sequences of real numbers, a_i and b_i, each of length n:
  $(a_1b_1+a_2b_2+a_3b_3+\ldots+a_nb_n)^2 \le (a_1^2+a_2^2+a_3^2+\ldots+a_n^2)(b_1^2+b_2^2+b_3^2+\ldots+b_n^2)$ with equality holding iff $a_1:a_2:a_3: \ldots :a_n::b_1:b_2:b_3: \ldots :b_n$.
- Chebyshev's Inequality- If $0 \le a_1 \le a_2 \le a_3 \le \ldots \le a_n$, $0 \le b_1 \le b_2 \le b_3 \le \ldots \le b_n$, then:
  $(a_1+a_2+a_3+\ldots+a_n)(b_1+b_2+b_3+\ldots+b_n) \le n \cdot (a_1b_1+a_2b_2+a_3b_3+\ldots+a_nb_n)$
- Jensen's Inequality- For a convex function f(x): $f(a_1)+f(a_2)+f(a_3)+\ldots+f(a_n) \ge n \cdot f\left(\frac{a_1+a_2+\ldots+a_n}{n}\right)$. More generally, if $b_1+b_2+\ldots+b_n=1$ and $b_i>0$, then: $b_1f(a_1)+b_2f(a_2)+b_3f(a_3)+\ldots+b_nf(a_n) \ge f(b_1a_1+b_2a_2+b_3a_3+\ldots+a_n)$

Section G – Number Systems

- $\mathbb{N}$ = natural numbers: 1, 2, 3, 4, 5, ...
- Algebraic numbers: numbers that can be solutions to polynomial equations with integer coefficients: $\sqrt{2}$, $\sqrt[5]{23}$, $\sqrt{\sqrt[5]{23}+\sqrt[7]{5}}$, ...
- Transcendental numbers: numbers that cannot be solutions to polynomials: e, π, ...
  - π is the ratio of the length of the circumference to the length of the diameter of a circle
  - $e = \lim_{x\to\infty}\left(\left(1+\frac{1}{x}\right)^x\right)$
- if we define the square root of –1 to be i, then:
  - $\mathbb{C}$ = complex numbers = a+bi, where $a,b \in R$

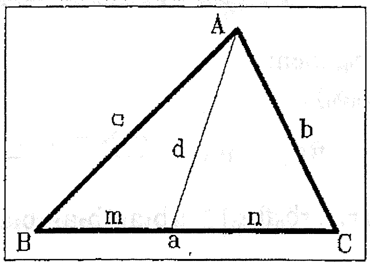
Complex Numbers in Rectangular & Polar		
		$a^2+b^2=r^2$; $\tan\theta = b/a$; $a = r \cdot \cos\theta$; $b = r \cdot \sin\theta$ $Z = a+bi = r \cdot \text{cis}\,\theta$ (polar form of a complex number) The magnitude of Z, represented by $\lvert a+bi \rvert = \sqrt{a^2+b^2}$
	$e^{i\theta} = \cos\theta + i\sin\theta = \text{cis}\,\theta$	$\text{cis}(\theta+\gamma) = \text{cis}\,\theta \cdot \text{cis}\,\gamma$
	$(a+bi)^n = (r\,\text{cis}\,\theta)^n = r^n \cdot \text{cis}(n\theta)$	$\text{cis}(\theta-\gamma) = \frac{\text{cis}\,\theta}{\text{cis}\,\gamma}$

Used with permission from:

www.nysml.org/Files/Formulas.pdf

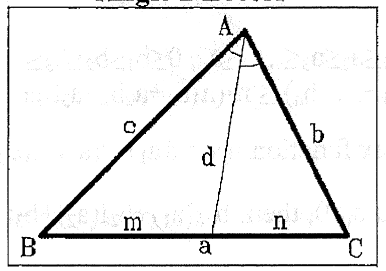
Section H – Euclidean Geometry I (The Triangle)

Stewart's Theorem



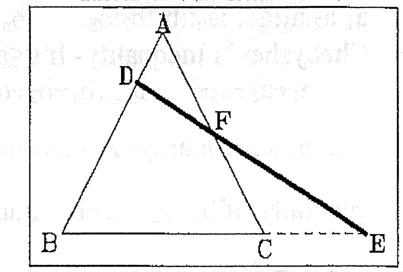
$man + dad = bmb + cnc$

Angle Bisector



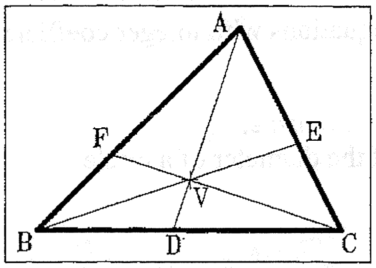
$bm = cn;\quad d^2 = bc - mn$

Menelaus' Theorem



$\overline{AD}\,\overline{BE}\,\overline{CF} = \overline{DB}\,\overline{EC}\,\overline{FA}$

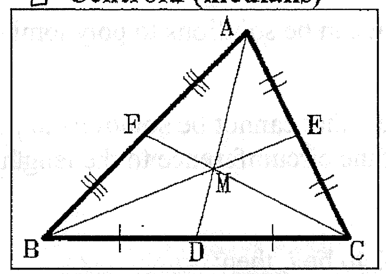
Ceva's Theorem



$\overline{AF}\,\overline{BD}\,\overline{CE} = \overline{AE}\,\overline{BF}\,\overline{CD}$

$\frac{\overline{VD}}{\overline{AD}} + \frac{\overline{VE}}{\overline{BE}} + \frac{\overline{VF}}{\overline{CF}} = 1$

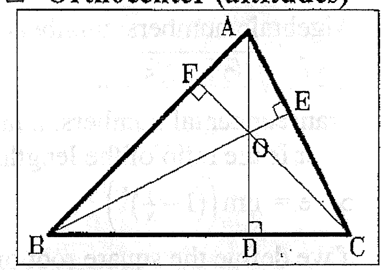
Centroid (medians)



$\frac{\overline{AM}}{\overline{MD}} = \frac{\overline{BM}}{\overline{ME}} = \frac{\overline{CM}}{\overline{MF}} = 2$

$K_{AFM} = K_{FBM} = K_{BDM} = K_{DCM} = K_{CEM} = K_{EAM} = \frac{1}{6}K_{ABC}$

Orthocenter (altitudes)

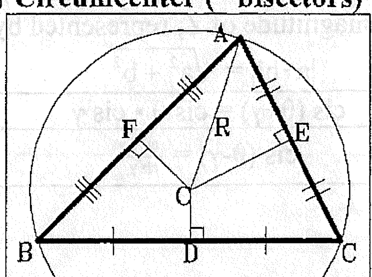


$\Delta_{AFC} \sim \Delta_{AEB} \sim \Delta_{OEC} \sim \Delta_{OFB}$

$\Delta_{BDA} \sim \Delta_{BFC} \sim \Delta_{OFA} \sim \Delta_{ODC}$

$\Delta_{CEB} \sim \Delta_{CDA} \sim \Delta_{ODB} \sim \Delta_{OEA}$

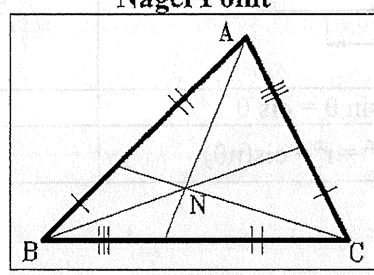
Circumcenter ($\perp$bisectors)



$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C} = 2R$

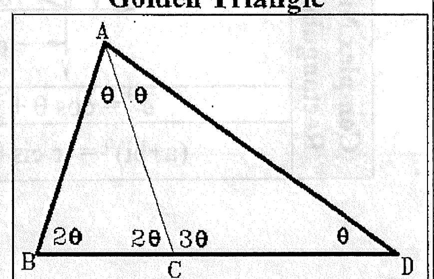
Extended Law of Sines

Nagel Point



Joins semi-perimeter points to vertices

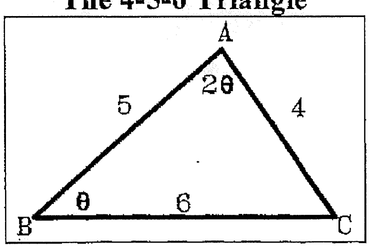
Golden Triangle



$\Delta_{ABC} \sim \Delta_{DAB};\ \theta = 36° = \pi/5$

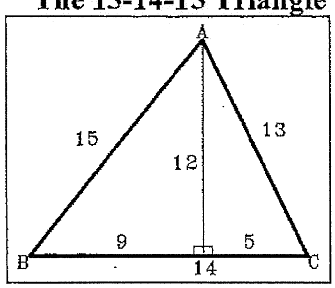
$\frac{\overline{CD}}{\overline{BC}} = \frac{\overline{BC}+\overline{CD}}{\overline{CD}} = \frac{\sqrt{5}+1}{2}$

The 4-5-6 Triangle



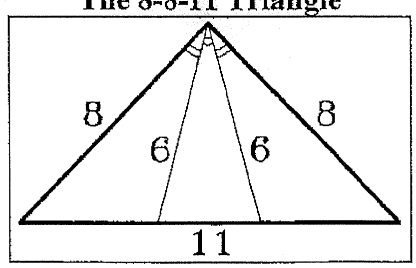
$A = 2B;\quad K = \frac{15\sqrt{7}}{4}$

The 13-14-15 Triangle



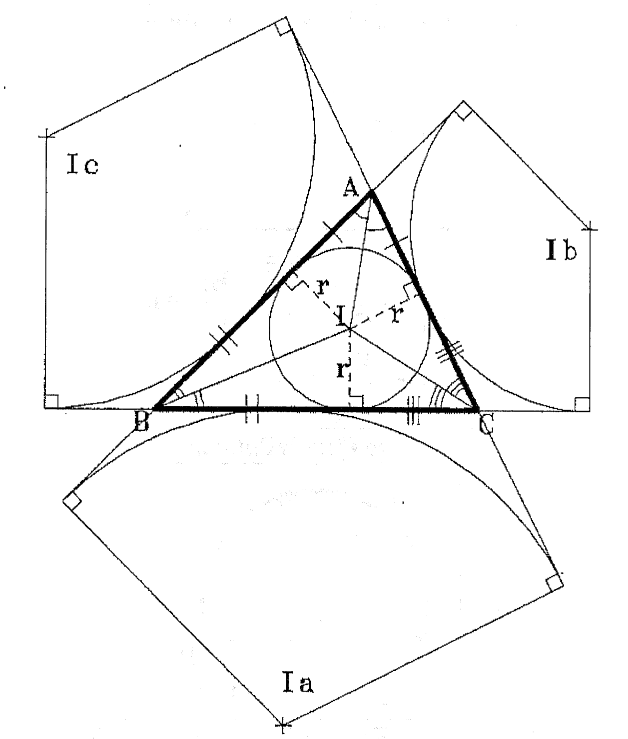
$K = 84;\ R = \frac{65}{8};\ r = 4$

The 8-8-11 Triangle



Trisectors of the largest angle has length 6

Appendix II - The "Elusive Formulas" continued



A Triangle and Its Circles

Δ_{ABC} has sides a, b and c and angles A, B, and C.
The radius of the inscribed circle is r.
The radius of the circumscribed circle is R.
The area of the triangle is K.
The semi-perimeter of the triangle is s.
The altitude to sides a, b, c are h_a, h_b, h_c respectively.
The angle bisectors to angles A, B, C are t_a, t_b, t_c respectively.
The medians to side a, b, c are m_a, m_b, m_c respectively.
The circles tangent to each line $\overleftrightarrow{AB}$, $\overleftrightarrow{BC}$, $\overleftrightarrow{CA}$ and directly next to sides a, b, c are called ex-circles I_a, I_b, I_c respectively.
The radii to ex-circles I_a, I_b, I_c are r_a, r_b, r_c respectively.
The distance from I to circumcenter is d.

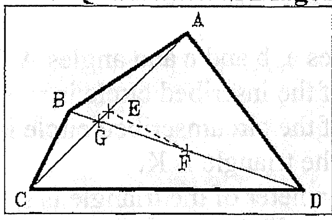
Area Formulas of the Triangle					
$K=\frac{c\ \ h_c}{2}$	$K=\frac{ab\sin C}{2}$	$K=\frac{c^2\sin A\sin B}{2\sin C}$	$K=\frac{abc}{4R}$	$K=rs$	$K=\sqrt{s(s-a)(s-b)(s-c)}$
For planar triangle with vertices $P_1(x_1, y_1)$, $P_2(x_2, y_2)$, $P_3(x_3\ y_3)$					
$K=\frac{1}{2}\begin{pmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{pmatrix}$			Coordinates of the centroid are $\left(\frac{x_1+x_2+x_3}{3}, \frac{y_1+y_2+y_3}{3}\right)$		

Basic Edge Inequalities	a+b>c, b+c>a, c+a>b
Basic Angle Identities	A+B+C = 180°, $\{a,b,c\}\subset(0,\pi)$
Law of Cosines	$a^2+b^2=c^2+2ab\cos C$
Law of Tangents	tan(A)tan(B)tan(C) = tan(A)+tan(B)+tan(C)

Assorted Identities			
$r_ar_b+r_br_c+r_cr_a=s^2$	$D^2=R^2-2Rr$	$4m_c^2=2a^2+2b^2+c^2$	$r_a+r_b+r_c-r=4R$
$r=\frac{c\sin\frac{A}{2}\sin\frac{B}{2}}{\cos\frac{C}{2}}$	$r_c=\frac{K}{s-c}$	$r^2=\frac{(s-a)(s-b)(s-c)}{s}$	$\frac{1}{r}=\frac{1}{r_a}+\frac{1}{r_b}+\frac{1}{r_c}$
$\sin\frac{C}{2}=\sqrt{\frac{(s-a)(s-b)}{ab}}$	$\tan\frac{C}{2}=\frac{r}{s-c}$	$\tan\frac{C}{2}=\sqrt{\frac{(s-a)(s-b)}{s(s-c)}}$	$\cos\frac{C}{2}=\sqrt{\frac{s(s-c)}{ab}}$
$t_c=\frac{2\sqrt{a\ b\ s(s-c)}}{a+b}$	$t_c=\frac{2ab\cos\frac{C}{2}}{a+b}$	$\frac{3}{4}\le\frac{m_a+m_b+m_c}{a+b+c}\le 1$	$\frac{a-b}{a+b}=\frac{\tan\left(\frac{A-B}{2}\right)}{\tan\left(\frac{A+B}{2}\right)}$

Section I – Euclidean Geometry II (The Quadrilateral)

General Quadrilateral Diagonals



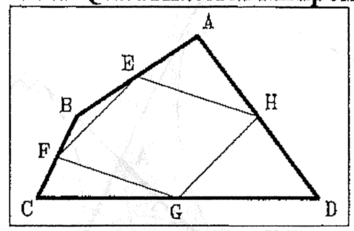
E and F are midpoints of $\overline{AC}$ and $\overline{BD}$

$K_{GAB} \cdot K_{GCD} = K_{GBC} \cdot K_{GDA}$

$K = \frac{1}{2}\overline{AC}\ \overline{BD} \sin \quad AGB$

$\overline{AB}^2 + \overline{BC}^2 + \overline{CD}^2 + \overline{DA}^2 = \overline{AC}^2 + \overline{BD}^2 + 4\overline{EF}^2$

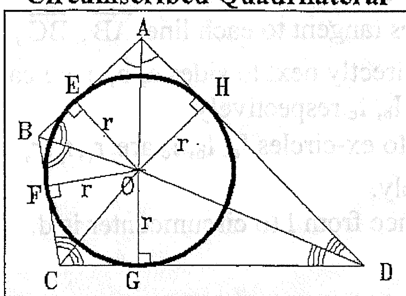
General Quadrilateral Midpoints



If $\frac{\overline{AH}}{\overline{HD}} = \frac{\overline{DG}}{\overline{GC}} = \frac{\overline{CF}}{\overline{FB}} = \frac{\overline{BE}}{\overline{EA}} = n$

Then: $\frac{K_{EFGH}}{K_{ABCD}} = \frac{n^2+1}{(n+1)^2}$

Circumscribed Quadrilateral

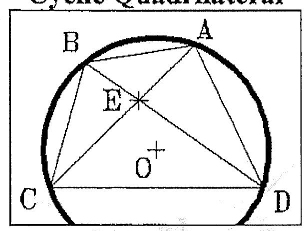


$\overline{AB} + \overline{CD} = \overline{BC} + \overline{AD} = s$; $K_{ABCD} = rs$

If $Quad_{ABCD}$ is also cyclic, then

$K = \sqrt{\overline{AB}\ \overline{CD}\ \overline{BC}\ \overline{AD}}$

Cyclic Quadrilateral



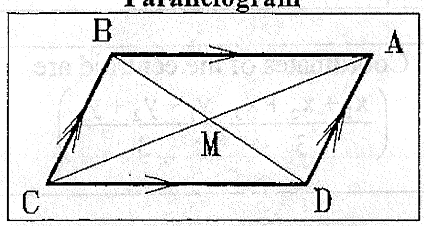
$A + C = B + D = 180°$

$K_{ABCD} = \sqrt{\left(s-\overline{AB}\right)\left(s-\overline{BC}\right)\left(s-\overline{CD}\right)\left(s-\overline{DA}\right)}$

$\overline{BC}\ \overline{AD} + \overline{AB}\ \overline{CD} = \overline{BD}\ \overline{AC}$

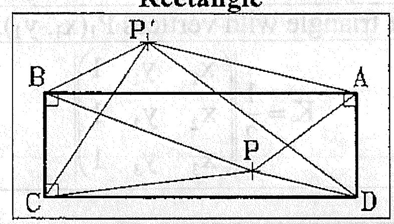
$\overline{AC}\left(\overline{BC}\ \overline{CD} + \overline{DA}\ \overline{AB}\right) = \overline{BD}\left(\overline{AB}\ \overline{BC} + \overline{CD}\ \overline{DA}\right)$

Parallelogram



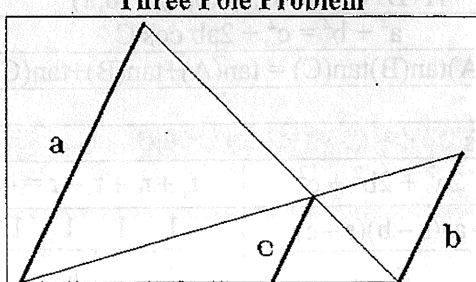
$2(\overline{BC}^2 + \overline{BA}^2) = \overline{BD}^2 + \overline{AC}^2$

Rectangle



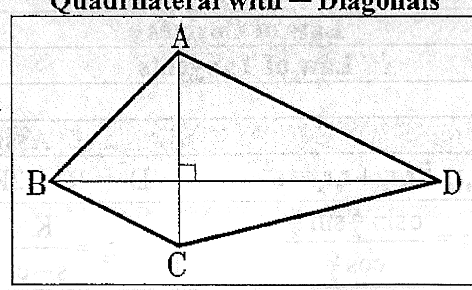
For all point P: $\overline{PA}^2 + \overline{PC}^2 = \overline{PB}^2 + \overline{PD}^2$

Three Pole Problem



if a || b || c, then $\frac{1}{a} + \frac{1}{b} = \frac{1}{c}$

Quadrilateral with ⊥ Diagonals



$\overline{AC} \perp \overline{BD} \Rightarrow K = \frac{1}{2}\overline{AC}\ \overline{BD}$

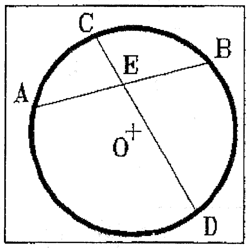
$\overline{AB}^2 + \overline{CD}^2 = \overline{BC}^2 + \overline{DA}^2$

Ptolemy's Theorem:

In any $Quad_{ABCD}$, $\overline{BD} \quad \overline{AC} \le \overline{BC} \quad \overline{AD} + \overline{AB} \quad \overline{CD}$, with equality holding iff $Quad_{ABCD}$ is cyclic.

Section J – Euclidean Geometry III (The Circle)

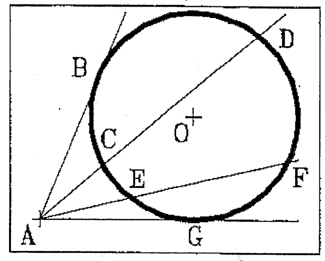
Circles



$AEC = \quad BED = \frac{1}{2}\left(AC+BD\right)$

Power of the point: $\overline{AE} \quad \overline{BE} = \overline{CE} \quad \overline{DE}$

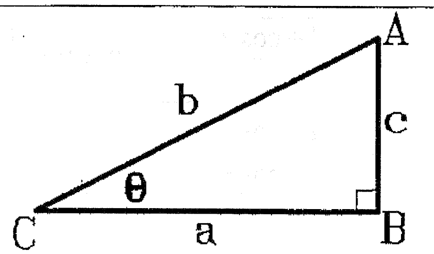
Circles 2



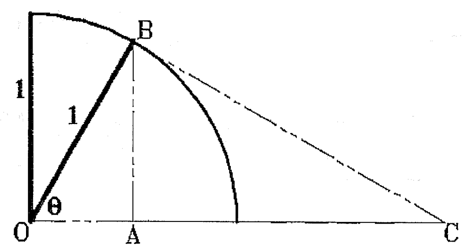
$\overline{AB} = \overline{AG}$; $\quad DAF = \frac{1}{2}\left(DF - CE\right)$

$\overline{AB}^2 = \overline{AD} \quad \overline{AC} = \overline{AF} \quad \overline{AE}$

Section K – Trigonometry



$\sin\theta = c/b$; $\cos\theta = a/b$; $\tan\theta = c/a$



$\sin\theta = \overline{AB}$; $\cos\theta = \overline{OA}$; $\tan\theta = \overline{BC}$

θ	15°	18°	30°	36°	45°	54°	60°	75°
sin θ	$\frac{\sqrt{6}-\sqrt{2}}{4}$	$\frac{\sqrt{5}-1}{4}$	$1/2$	$\frac{\sqrt{2(5-\sqrt{5})}}{4}$	$\sqrt{2}/2$	$\frac{\sqrt{5}+1}{4}$	$\sqrt{3}/2$	$\frac{\sqrt{6}+\sqrt{2}}{4}$
cos θ	$\frac{\sqrt{6}+\sqrt{2}}{4}$	$\frac{\sqrt{2(5+\sqrt{5})}}{4}$	$\sqrt{3}/2$	$\frac{\sqrt{5}+1}{4}$	$\sqrt{2}/2$	$\frac{\sqrt{2(5-\sqrt{5})}}{4}$	$1/2$	$\frac{\sqrt{6}-\sqrt{2}}{4}$
tan θ	$2-\sqrt{3}$	$\frac{(\sqrt{5}-1)\sqrt{2}}{2\sqrt{5+\sqrt{5}}}$	$\sqrt{3}/3$	$\frac{\sqrt{2(5-\sqrt{5})}}{\sqrt{5}+1}$	1	$\frac{(\sqrt{5}+1)\sqrt{2}}{2\sqrt{5-\sqrt{5}}}$	$\sqrt{3}$	$2+\sqrt{3}$

Pythagorean	Odd-Even Functions	Summation of Angles
$\sin^2\theta + \cos^2\theta = 1$	$\sin(-\theta) = -\sin(\theta)$	$\sin(\theta \pm \gamma) = \sin(\theta)\cos(\gamma) \pm \cos(\theta)\sin(\gamma)$
$1 + \tan^2\theta = \sec^2\theta$	$\cos(-\theta) = \cos(\theta)$	$\cos(\theta \pm \gamma) = \cos(\theta)\cos(\gamma) \mp \sin(\theta)\sin(\gamma)$
$1 + \cot^2\theta = \csc^2\theta$	$\tan(-\theta) = -\tan(\theta)$	$\tan(\theta \pm \gamma) = \frac{\tan(\theta) \pm \tan(\gamma)}{1 \mp \tan(\theta)\tan(\gamma)}$

Multiple Angles			
	$\sin 2\theta = 2\sin\theta\cos\theta$	$\sin 3\theta = 3\sin\theta - 4\sin^3\theta$	$\sin 4\theta = 4\cdot\sin\theta\cdot\cos\theta\cdot(\cos^3\theta - \sin\theta)$
	$\cos 2\theta = \cos^2\theta - \sin^2\theta$	$\cos 3\theta = 4\cos^3\theta - 3\cos\theta$	$\cos 4\theta = \sin^4\theta + \cos^4\theta - 6\cos^2\theta\cdot\sin^2\theta$
	$\tan 2\theta = \frac{2\tan\theta}{1-\tan^2\theta}$	$\tan 3\theta = \frac{\tan^3\theta - 3\tan\theta}{3\tan^2\theta - 1}$	$\tan 4\theta = \frac{4\tan\theta(1-\tan^2\theta)}{\tan^4\theta - 6\tan^2\theta + 1}$

Sum to Product	Product to Sum
$\sin\theta \pm \sin\gamma = 2\sin\left(\frac{\theta\pm\gamma}{2}\right)\cos\left(\frac{\theta\mp\gamma}{2}\right)$	$\sin\theta \cdot \sin\gamma = \frac{1}{2}[\cos(\theta-\gamma) - \cos(\theta+\gamma)]$
$\cos\theta + \cos\gamma = 2\cos\left(\frac{\theta+\gamma}{2}\right)\cos\left(\frac{\theta-\gamma}{2}\right)$	$\cos\theta \cdot \cos\gamma = \frac{1}{2}[\cos(\theta-\gamma) + \cos(\theta+\gamma)]$
$\cos\theta - \cos\gamma = -2\sin\left(\frac{\theta+\gamma}{2}\right)\sin\left(\frac{\theta-\gamma}{2}\right)$	$\sin\theta \cdot \cos\gamma = \frac{1}{2}[\sin(\theta-\gamma) + \sin(\theta+\gamma)]$
$\tan\theta \pm \tan\gamma = \frac{\sin(\theta\pm\gamma)}{\cos\theta \quad \cos\gamma}$	$\tan\theta \cdot \tan\gamma = \frac{\cos(\theta-\gamma)-\cos(\theta+\gamma)}{\cos(\theta-\gamma)+\cos(\theta+\gamma)}$

Square Identities	Cube Identities	½ Angle Identities	tan (θ/2) Identities
$\sin^2\theta = \frac{1}{2}(1-\cos 2\theta)$	$\sin^3\theta = \frac{3\sin\theta - \sin 3\theta}{4}$	$\sin\theta/2 = \pm\sqrt{\frac{1-\cos\theta}{2}}$	$\sin\theta = \frac{2\tan\frac{\theta}{2}}{1+\tan^2\frac{\theta}{2}}$
$\cos^2\theta = \frac{1}{2}(1+\cos 2\theta)$	$\cos^3\theta = \frac{3\cos\theta + \cos 3\theta}{4}$	$\cos\theta/2 = \pm\sqrt{\frac{1+\cos\theta}{2}}$	$\cos\theta = \frac{1-\tan^2\frac{\theta}{2}}{1+\tan^2\frac{\theta}{2}}$
$\tan^2\theta = \frac{1-\cos 2\theta}{1+\cos 2\theta}$	$\tan^3\theta = \frac{3\sin\theta - \sin 3\theta}{3\cos\theta + \cos 3\theta}$	$\tan\theta/2 = \pm\sqrt{\frac{1+\cos\theta}{1-\cos\theta}}$	

Authors:

Ming Jack Po (Johns Hopkins University)
Kevin Zheng (Carnegie Mellon University)

Proof Readers:

Jan Siwanowicz (City College of New York)
Jeff Amlin (Harvard University)
Kamaldeep Gandhi (Brooklyn Polytechnic University)
Joel Lewis (Harvard University)
Seth Kleinerman (Harvard University)

Programs Used:

Math Type 4, 5
CadKey 5
Geometer's Sketchpad 3, 4
Microsoft Word XP
Mathematica 4.1

References:

IMSA – Noah Sheets
Bronx Science High School – Formula Sheets, Math Bulletin