

**Individual Events**

<b>I1</b>	$A$	80	<b>I2</b>	$A$	2	<b>I3</b>	$s$	$\frac{25}{4}$	<b>I4</b>	$\alpha$	$\frac{5}{8}$
	$B$	7		$B$	3		$t$	6		$\beta$	4
	$C$	15		$C$	$\frac{11}{50}$		$u$	1		$\gamma$	45
	$D$	$\frac{125}{36} = 3\frac{17}{36}$		$D$	3		$v$	4		$\delta$	16

**Group Events**

<b>G1</b>	$a$	8	<b>G2</b>	least $A$	7056	<b>G3</b>	least $a$	14	<b>G4</b>	$\alpha$	24
	$b$	6		$B$	6		$e$	27		$\beta$	7333
	$c$	24		least $Q$	1		$c$	45		$\gamma$	$\frac{9}{5} = 1.8$
	$d$	419		$W$	5		$d$	3		$\delta$	0.01

**Individual Event 1**

**11.1** 若  $A$  是  $(x^2 + 2)^5$  展開式中  $x^4$  的係數，求  $A$  的值。

If  $A$  is the coefficient of  $x^4$  in the expansion of  $(x^2 + 2)^5$ , determine the value of  $A$ .

$$A = C_2^5 (2)^3 = 80$$

**11.2** 若  $x$  和  $y$  為正整數，並且滿足以下等式  $\log_{10} x + \log_{10} y = \log_{10} (2x - Ay) + 1$ ，

而  $B$  是  $(x, y)$  所有可能組合的數量，求  $B$  的值。

If  $x$  and  $y$  are positive integers that satisfy  $\log_{10} x + \log_{10} y = \log_{10} (2x - Ay) + 1$ ,

and  $B$  is the number of possible pairs of  $(x, y)$ , determine the value of  $B$ .

$\log_{10} x + \log_{10} y = \log_{10} (2x - 80y) + 1$ $\log_{10} (xy) = \log_{10} 10(2x - 80y)$ $xy = 20x - 800y$ $20x - xy - 800y + 16000 = 16000$ $x(20 - y) + 800(20 - y) = 16000$ $(x + 800)(20 - y) = 16000$ $x$ 和 $y$ 為正整數， $(x + 800, 20 - y)$ $= (16000, 1), (8000, 2), (4000, 4), (3200, 5),$ $(2000, 8), (1600, 10), (1000, 16)$ 一共有 7 組答案 $(x, y)$ 。 $B = 7$	$\log_{10} x + \log_{10} y = \log_{10} (2x - 80y) + 1$ $\log_{10} (xy) = \log_{10} 10(2x - 80y)$ $xy = 20x - 800y$ $20x - xy - 800y + 16000 = 16000$ $x(20 - y) + 800(20 - y) = 16000$ $(x + 800)(20 - y) = 16000$ For positive integral values $(x + 800, 20 - y)$ $= (16000, 1), (8000, 2), (4000, 4), (3200, 5),$ $(2000, 8), (1600, 10), (1000, 16)$ There are 7 pairs of $(x, y)$ . $B = 7$
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**11.3** 若  $Y = 2^{3(B-1)}$  並且  $C$  是  $Y$  中每個數字之和，求  $C$  的值。

If  $Y = 2^{3(B-1)}$  and  $C$  is the sum of the digits of  $Y$ , determine the value of  $C$ .

$$Y = 2^{3(7-1)} = 2^{18} = 262144$$

$$C = 2 + 6 + 2 + 1 + 4 + 4 = 19$$

**11.4** 在  $\triangle XYZ$  中，已知  $XY \perp YZ$ ， $\angle XZY = \theta$ ，線段  $YZ$  和  $XZ$  的長度分別為  $C - 3$  和  $C + 5$ 。

若  $D = (\sin \theta + \tan \theta)^2$ ，求  $D$  的值。

In  $\triangle XYZ$ ,  $XY \perp YZ$ ,  $\angle XZY = \theta$ , and the length of  $YZ$  and  $XZ$  are  $C - 3$  and  $C + 5$  respectively. If  $D = (\sin \theta + \tan \theta)^2$ , determine the value of  $D$ .

$$YZ = 19 - 3 = 16$$

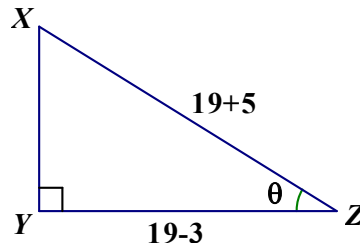
$$XZ = 19 + 5 = 24$$

$$XY^2 + 16^2 = 24^2$$

$$XY = \sqrt{320} = 8\sqrt{5}$$

$$\sin \theta = \frac{8\sqrt{5}}{24} = \frac{\sqrt{5}}{3}; \tan \theta = \frac{8\sqrt{5}}{16} = \frac{\sqrt{5}}{2}$$

$$D = \left( \frac{\sqrt{5}}{3} + \frac{\sqrt{5}}{2} \right)^2 = \frac{125}{36} = 3\frac{17}{36}$$



**Individual Event 2**

**12.1** 若  $\sqrt{A} = \sqrt{11+\sqrt{21}} - \sqrt{11-\sqrt{21}}$ ，求  $A$  的值。

If  $\sqrt{A} = \sqrt{11+\sqrt{21}} - \sqrt{11-\sqrt{21}}$ , determine the value of  $A$ .

**Reference: 2007 FI1.1, 2016 FI1.2**

$$\begin{aligned} A &= \left( \sqrt{11+\sqrt{21}} - \sqrt{11-\sqrt{21}} \right)^2 \\ &= 11+21 - 2\left( \sqrt{11+\sqrt{21}} \cdot \sqrt{11-\sqrt{21}} \right) + 11-21 \\ &= 22 - 2\sqrt{121-21} = 22 - 2 \times 10 = 2 \end{aligned}$$

**12.2** 若直線  $y = mx + B$  經過兩點  $(4, 5)$  和  $(-A, A)$ ，求  $B$  的值。

If the straight line  $y = mx + B$  passes through the two points  $(4, 5)$  and  $(-A, A)$ , determine the value of  $B$ .

$$m = \frac{5-2}{4+2} = \frac{1}{2}$$

$$B = y - mx = 5 - \frac{1}{2} \times 4 = 3$$

**12.3** 若  $\cos x + \sin x = \frac{2B}{5}$  及  $C = (\tan x + \cot x)^{-1}$ ，求  $C$  的值。

If  $\cos x + \sin x = \frac{2B}{5}$  and  $C = (\tan x + \cot x)^{-1}$ , determine the value of  $C$ .

**Reference: 1992 HI20, 1993 HG10, 1995 HI5, 2007 HI7, 2007 FI1.4, 2014 HG3**

$$\cos x + \sin x = \frac{2 \times 3}{5} = \frac{6}{5}$$

$$(\cos x + \sin x)^2 = \frac{36}{25}$$

$$1 + 2 \sin x \cos x = \frac{36}{25} \Rightarrow \sin x \cos x = \frac{11}{50}$$

$$C = (\tan x + \cot x)^{-1} = \left( \frac{\sin x}{\cos x} + \frac{\cos x}{\sin x} \right)^{-1} = \left( \frac{\sin^2 x + \cos^2 x}{\cos x \sin x} \right)^{-1} = \sin x \cos x = \frac{11}{50}$$

**12.4** 假設  $D, x, y$  和  $z$  均為整數，其中  $D > x > y > z$ 。

若  $D, x, y$  和  $z$  滿足等式  $3^D - 3^x + 3^y - 3^z = \frac{1000C+2}{9}$ ，求  $D$  的值。

Suppose that  $D, x, y$  and  $z$  are integers with  $D > x > y > z$ . If  $D, x, y$  and  $z$  satisfy the equation  $3^D - 3^x + 3^y - 3^z = \frac{1000C+2}{9}$ , determine the value of  $D$ .

**Reference: 2003 FI4.3**

$$\frac{1000C+2}{9} = \frac{1000 \times \frac{11}{50} + 2}{9} = 24 \frac{2}{3} = 27 - 3 + 1 - \frac{1}{3}$$

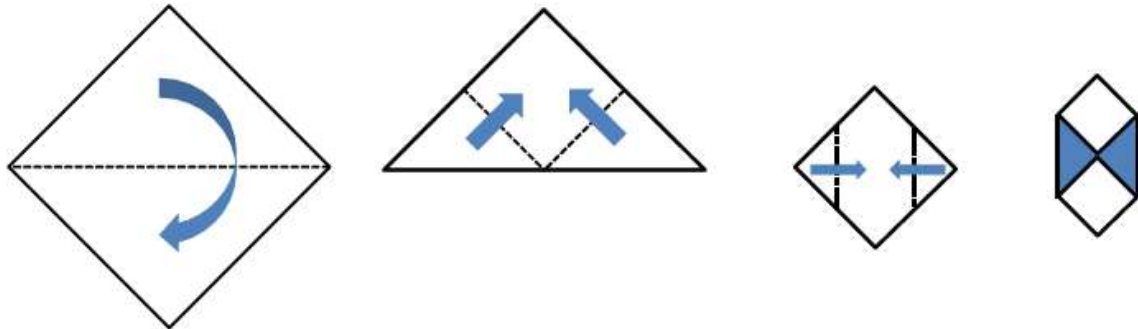
$$D = 3, x = 1, y = 0, z = -1$$

### Individual Event 3

**13.1** 一張正方形紙的面積為  $100 \text{ cm}^2$ ，按照圖中的虛線和箭咀的方向對摺。

若圖中的陰影部份為  $s \text{ cm}^2$ ，求  $s$  的值。

A piece of **square** paper of area  $100 \text{ cm}^2$ , is folded in half along the dotted line as shown below. If the area of the shaded region in the last figure is  $s \text{ cm}^2$ , determine the value of  $s$ .



由左至右，第二幅圖的面積為 $50 \text{ cm}^2$ ，第三幅圖的面積為 $25 \text{ cm}^2$ 。	Starting from left to right, the second diagram has an area $50 \text{ cm}^2$ , the third diagram has an area $25 \text{ cm}^2$ . The shaded area $= 25 \times \frac{2}{8} \text{ cm}^2 = \frac{25}{4} \text{ cm}^2$
陰影面積 $= 25 \times \frac{2}{8} \text{ cm}^2 = \frac{25}{4} \text{ cm}^2$	
$s = \frac{25}{4}$	$s = \frac{25}{4}$

**13.2** 假設  $s = \frac{A}{B}$  為最簡分數。若  $c$  和  $d$  分別為  $A$  和  $B$  的正因數的數量，求  $t = c + d$  的值。

Suppose that  $s = \frac{A}{B}$  is in simplest form. If  $c$  and  $d$  are the number of positive factors of  $A$  and  $B$  respectively, determine the value of  $t = c + d$ .

$s = \frac{25}{4}$ , $A = 25$ , $B = 4$	$s = \frac{25}{4}$ , $A = 25$ , $B = 4$
25 的正因數是 1、5、25。	Positive factors of 25 are 1, 5, 25.
4 的正因數是 1、2、4。	Positive factors of 4 are 1, 2, 4.
$t = 3 + 3 = 6$	$t = 3 + 3 = 6$

**13.3** 若今天是某一週的第 2 日，以及已知  $t^{2019}$  日後的當天為該週的第  $u$  日，求  $u$  的值。

If today is the 2<sup>nd</sup> day of a week, and it is known that  $t^{2019}$  days later is the  $u^{\text{th}}$  day of the week, determine the value of  $u$ .

$$\begin{aligned}
 6^{2019} &= (7 - 1)^{2019} \\
 &= 7^{2019} - 2019 \times 7^{2018} + \dots + (-1)^{2019} \text{ (binomial expansion 二項式展開)} \\
 &= 7m - 1 \\
 u &= -1 + 2 = 1
 \end{aligned}$$

**13.4** 若  $v_{(u+5)}$  為  $1231234_{(u+5)} \div 123_{(u+5)}$  的餘數，求  $v$  的值。

If  $v_{(u+5)}$  is the remainder of  $1231234_{(u+5)} \div 123_{(u+5)}$ , determine the value of  $v$ .

**Reference: 2018 FG1.4**

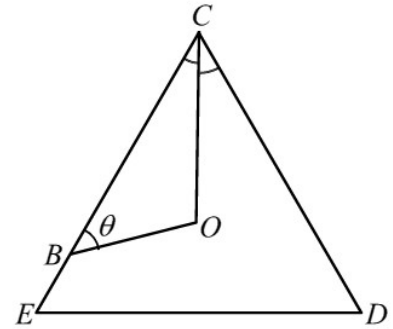
$$1231234_6 = 1230000_6 + 1230_6 + 4_6$$

$$v = 4$$

### Individual Event 4

**I4.1**  $\triangle CDE$  為一個等邊三角形。點  $O$  在  $\triangle CDE$  內。若點  $B$  在  $CE$  上， $\theta = \angle CBO$ ， $OC$  為  $\angle DCE$  的角平分綫，以及  $OC : OB = 5 : 4$ ，求  $\alpha = \sin \theta$  的值。

$\triangle CDE$  is an equilateral triangle. Point  $O$  is inside  $\triangle CDE$ . If point  $B$  lies on  $CE$ ,  $\theta = \angle CBO$ ,  $\angle DCE$  is bisected by  $OC$ , and  $OC : OB = 5 : 4$ , determine the value of  $\alpha = \sin \theta$ .



$\angle BCO = \angle DCO = 30^\circ$ 設 $OB = 4k$ , $OC = 5k$ 於 $\triangle BOC$ 應用正弦定理， $\frac{\sin \theta}{5k} = \frac{\sin 30^\circ}{4k}$ $\alpha = \sin \theta = \frac{5}{8}$	$\angle BCO = \angle DCO = 30^\circ$ Let $OB = 4k$ , $OC = 5k$ Apply sine rule on $\triangle BOC$ , $\frac{\sin \theta}{5k} = \frac{\sin 30^\circ}{4k}$ $\alpha = \sin \theta = \frac{5}{8}$
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**I4.2** 假設有一函數  $f(x)$ ，對於任何整數  $x$  及任何整數  $y \neq 0$ ，

均滿足  $f\left(\frac{x}{y}\right) = f(x) - f(y)$  和  $f(2) = -1$ 。若  $\beta = f\left(\frac{\alpha}{10}\right)$ ，求  $\beta$  的值。

Suppose that there exists a function  $f(x)$ , defined for all integers  $x$  and for all integers  $y \neq 0$ , such that  $f\left(\frac{x}{y}\right) = f(x) - f(y)$  and  $f(2) = -1$ . If  $\beta = f\left(\frac{\alpha}{10}\right)$ , determine the value of  $\beta$ .

$$f(2) = f\left(\frac{2}{1}\right) = f(2) - f(1) \Rightarrow f(1) = 0$$

$$-1 = f(2) = f\left(\frac{4}{2}\right) = f(4) - f(2) = f(4) + 1 \Rightarrow f(4) = -2$$

$$-2 = f(4) = f\left(\frac{8}{2}\right) = f(8) - f(2) = f(8) + 1 \Rightarrow f(8) = -3$$

$$-3 = f(8) = f\left(\frac{16}{2}\right) = f(16) - f(2) = f(16) + 1 \Rightarrow f(16) = -4$$

$$\beta = f\left(\frac{\alpha}{10}\right) = f\left(\frac{5}{80}\right) = f\left(\frac{1}{16}\right) = f(1) - f(16) = -f(16) = 4$$

**14.3** 若  $B = \gamma p + 2\gamma(1-p)$  以及  $p = \frac{\beta(\gamma-40)}{100}$ , 當  $B$  取最大值時, 求  $\gamma$  的值。

If  $B = \gamma p + 2\gamma(1-p)$  and  $p = \frac{\beta(\gamma-40)}{100}$ , determine the value of  $\gamma$  such that  $B$  attains the maximum.

$$\begin{aligned} p &= \frac{4(\gamma-40)}{100} = \frac{\gamma-40}{25} \\ 1-p &= 1 - \frac{\gamma-40}{25} = \frac{65-\gamma}{25} \\ B &= \gamma \cdot \frac{\gamma-40}{25} + 2\gamma \cdot \frac{65-\gamma}{25} \\ &= -\frac{1}{25}(\gamma^2 - 90\gamma) \\ &= -\frac{1}{25}(\gamma-45)^2 + 81 \end{aligned}$$

When  $\gamma = 45$ ,  $B$  attains the maximum.

**14.4** 已知  $a$ 、 $b$  和  $c$  是  $\gamma$  的正因數, 而且  $a < b < c < \gamma$  及  $ab = c$ 。

若  $x + y = a$ ,  $x + 2y + z = b$ ,  $y + 2z + t = c$  及  $\delta = x + y + z + t$ , 求  $\delta$  的值。

**Given** that  $a$ ,  $b$  and  $c$  are positive factors of  $\gamma$  with  $a < b < c < \gamma$  and  $ab = c$ .

If  $x + y = a$ ,  $x + 2y + z = b$ ,  $y + 2z + t = c$  and  $\delta = x + y + z + t$ , determine the value of  $\delta$ .

$a = 3, b = 5, c = 15$	$a = 3, b = 5, c = 15$
$x + y = 3$ ..... (1)	$x + y = 3$ ..... (1)
$x + 2y + z = 5$ ..... (2)	$x + 2y + z = 5$ ..... (2)
$y + 2z + t = 15$ ..... (3)	$y + 2z + t = 15$ ..... (3)
由(1)式, $y = 3 - x$ ..... (4)	From (1), $y = 3 - x$ ..... (4)
代(4)式入(2)式, $x + 2(3 - x) + z = 5$	Sub. (4) into (2), $x + 2(3 - x) + z = 5$
$z = -1 + x$ ..... (5)	$z = -1 + x$ ..... (5)
代(4)式及(5)式入(3)式,	Sub. (4) and (5) into (3),
$3 - x + 2(-1 + x) + t = 15$	$3 - x + 2(-1 + x) + t = 15$
$1 + x + t = 15$	$1 + x + t = 15$
$t = 14 - x$ ..... (6)	$t = 14 - x$ ..... (6)
代(4)式、(5)式及(6)式入 $\delta = x + y + z + t$	Sub. (4), (5) and (6) into $\delta = x + y + z + t$
$\delta = x + (3 - x) + (-1 + x) + (14 - x) = 16$	$\delta = x + (3 - x) + (-1 + x) + (14 - x) = 16$

## Group Event 1

**G1.1** 已知  $x + y = 32$ ，其中  $x, y \geq 0$ 。若  $a$  為  $\sqrt{x} + \sqrt{y}$  的最大值，求  $a$  的值。

Let  $x + y = 32$  with  $x, y \geq 0$ . If  $a$  is the maximum value of  $\sqrt{x} + \sqrt{y}$ , determine the value of  $a$ .

**Reference: 1999 FG3.4**

$$\begin{aligned} (\sqrt{x} + \sqrt{y})^2 &= x + 2\sqrt{x} \cdot \sqrt{y} + y \\ &= 32 + 2\sqrt{xy} \\ &\leq 32 + 2\left(\frac{x+y}{2}\right) \quad (\text{A.M.} \geq \text{G.M.}) \\ &= 32 + 32 = 64 \end{aligned}$$

$$a = 8$$

**G1.2** 一個盒中只有  $x$  個一元硬幣， $x+2$  個二元硬幣及  $x+4$  個五元硬幣。已知隨機從盒中拿出一元硬幣的概率小於 0.1。若盒中有  $b$  個硬幣，求  $b$  的值。

A box contains only  $x$ -one-dollar coins,  $x+2$  two-dollar coins and  $x+4$  five-dollar coins. Given that the probability of drawing a one-dollar coin randomly from the box is less than 0.1. If the box contains  $b$  coins, determine the value of  $b$ .

$$b = x + x + 2 + x + 4 = 3x + 6$$

$$\frac{x}{3x+6} < 0.1$$

$$10x < 3x + 6$$

$$7x < 6$$

$$x = 0$$

$$b = 3 \times 0 + 6 = 6$$

**G1.3** 若  $c$  是以下數的最大公因數， $3^3 - 3, 5^5 - 5, 7^7 - 7, 9^9 - 9, \dots, 2019^{2019} - 2019$ ，求  $c$  的值。

If  $c$  is the greatest common factor of the following numbers

$3^3 - 3, 5^5 - 5, 7^7 - 7, 9^9 - 9, \dots, 2019^{2019} - 2019$ , determine the value of  $c$ .

**Reference: Mathematics Excalibur Volume 6, Number 4 Problem Corner Problem 131**

$3^3 - 3 = 24$ , H.C.F. 最大是 24。 設 $n = 2k + 1$ ，其中 $k$ 為正整數。 $n^n - n = n(n^{n-1} - 1)$ $= n(n^{2k} - 1)$ $= n(n^2 - 1)[(n^2)^{k-1} + (n^2)^{k-2} + \dots + 1]$ $= (n-1)n(n+1)(n^{2k-2} + n^{2k-4} + \dots + 1)$ $(n-1)n(n+1)$ 為三個連續整數之積，因此必然被 3 整除。 另外， $(n-1)(n+1) = 2k(2k+2) = 4k(k+1)$ 由於 $k(k+1)$ 為兩個連續整數之積，因此必然被 2 整除。 $\therefore 4k(k+1)$ 能被 8 整除。 即是說， $(n-1)(n+1)$ 能被 8 整除。 由於 3 和 8 互質， $n^n - n$ 能被 $3 \times 8 = 24$ 整除。 H.C.F. = $c = 24$	$3^3 - 3 = 24$ , the H.C.F. is at most 24. Let $n = 2k + 1$ , where $k$ is a positive integer. $n^n - n = n(n^{n-1} - 1)$ $= n(n^{2k} - 1)$ $= n(n^2 - 1)[(n^2)^{k-1} + (n^2)^{k-2} + \dots + 1]$ $= (n-1)n(n+1)(n^{2k-2} + n^{2k-4} + \dots + 1)$ $(n-1)n(n+1)$ is the product of 3 consecutive integers, which is divisible by 3. Also, $(n-1)(n+1) = 2k(2k+2) = 4k(k+1)$ As $k(k+1)$ is the product of 2 consecutive integers, which must be divisible by 2. $\therefore 4k(k+1)$ is divisible by 8. i.e. $(n-1)(n+1)$ is divisible by 8. As 3 and 8 are relatively prime, $n^n - n$ is divisible by $3 \times 8 = 24$ . H.C.F. = $c = 24$
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**G1.4** 設  $x = \frac{\sqrt{5} + \sqrt{7}}{\sqrt{5} - \sqrt{7}}$  和  $y = \frac{\sqrt{5} - \sqrt{7}}{\sqrt{5} + \sqrt{7}}$ 。若  $d = 3x^2 - 7xy + 3y^2$ ，求  $d$  的值。

Let  $x = \frac{\sqrt{5} + \sqrt{7}}{\sqrt{5} - \sqrt{7}}$  and  $y = \frac{\sqrt{5} - \sqrt{7}}{\sqrt{5} + \sqrt{7}}$ . If  $d = 3x^2 - 7xy + 3y^2$ , determine the value of  $d$ .

**Reference: 2000 FG1.2**

$$x = \frac{\sqrt{5} + \sqrt{7}}{\sqrt{5} - \sqrt{7}} \times \frac{\sqrt{5} + \sqrt{7}}{\sqrt{5} + \sqrt{7}} = -\frac{12 + 2\sqrt{35}}{2} = -(6 + \sqrt{35})$$

$$y = \frac{\sqrt{5} - \sqrt{7}}{\sqrt{5} + \sqrt{7}} \times \frac{\sqrt{5} - \sqrt{7}}{\sqrt{5} - \sqrt{7}} = -\frac{12 - 2\sqrt{35}}{2} = -(6 - \sqrt{35})$$

$$x^2 = [-(6 + \sqrt{35})]^2 = 71 + 12\sqrt{35}; y^2 = 71 - 12\sqrt{35}; xy = [-(6 + \sqrt{35})][-(6 - \sqrt{35})] = 1$$

$$d = 3x^2 - 7xy + 3y^2 = 3(71 + 12\sqrt{35}) - 7 + 3(71 - 12\sqrt{35}) = 419$$



**Group Event 2****G2.1** 設  $X = \sqrt{2020 - \sqrt{A}}$  為正整數，求  $A$  的最小值。Let  $X = \sqrt{2020 - \sqrt{A}}$  be a positive integer. Determine the least value of  $A$ .**Reference: 2016 HI3, 2018FG4.1**

$45 = \sqrt{2025} > \sqrt{2020 - \sqrt{A}}$	$45 = \sqrt{2025} > \sqrt{2020 - \sqrt{A}}$
$X = \sqrt{2020 - \sqrt{A}} = 1, 2, \dots, 43$ 或 $44$	$X = \sqrt{2020 - \sqrt{A}} = 1, 2, \dots, 43$ or $44$
$2020 - \sqrt{A} = 1^2, 2^2, \dots, 43^2$ 或 $44^2$	$2020 - \sqrt{A} = 1^2, 2^2, \dots, 43^2$ or $44^2$
$\sqrt{A} = 2020 - 1^2, 2020 - 2^2, \dots$ 或 $2020 - 44^2$	$\sqrt{A} = 2020 - 1^2, 2020 - 2^2, \dots$ , or $2020 - 44^2$
$A = (2020 - 1^2)^2, (2020 - 2^2)^2, \dots$ 或 $(2020 - 44^2)^2$	$A = (2020 - 1^2)^2, (2020 - 2^2)^2, \dots$ , or $(2020 - 44^2)^2$
$A$ 的最小值 $= (2020 - 44^2)^2 = 84^2 = 7056$	The least value of $A = (2020 - 44^2)^2 = 84^2 = 7056$

**G2.2** 假設  $\begin{cases} x + y = 5 \\ 4x^2 + y^2 = 80 \end{cases}$ ，及  $P = (x_1, y_1)$  和  $Q = (x_2, y_2)$  為兩個不同的點，同時滿足這兩個等式。若  $B = y_1 - x_1 + y_2 - x_2$ ，求  $B$  的值。

Suppose that  $\begin{cases} x + y = 5 \\ 4x^2 + y^2 = 80 \end{cases}$ , and  $P = (x_1, y_1)$  and  $Q = (x_2, y_2)$  are two different points,

simultaneously satisfy these two equations. If  $B = y_1 - x_1 + y_2 - x_2$ , determine the value of  $B$ .

由(1)式， $y = 5 - x \cdots (3)$	From (1), $y = 5 - x \cdots (3)$
代(3)式入(2)式： $4x^2 + (5 - x)^2 = 80$	Sub. (3) into (2): $4x^2 + (5 - x)^2 = 80$
$4x^2 + 25 - 10x + x^2 = 80$	$4x^2 + 25 - 10x + x^2 = 80$
$5x^2 - 10x - 55 = 0$	$5x^2 - 10x - 55 = 0$
$x^2 - 2x - 11 = 0$ ，其根為 $x_1$ 及 $x_2$ 。	$x^2 - 2x - 11 = 0$ , the roots are $x_1$ and $x_2$ .
$x_1 + x_2 =$ 兩根之和 $= 2$	$x_1 + x_2 =$ sum of roots $= 2$
$(x_1, y_1)$ 及 $(x_2, y_2)$ 兩皆滿足 $y = 5 - x$	$(x_1, y_1)$ and $(x_2, y_2)$ both satisfy $y = 5 - x$
$y_1 + y_2 = 5 - (x_1 + x_2) = 5 - 2 = 3$	$y_1 + y_2 = 5 - (x_1 + x_2) = 5 - 2 = 3$
$B = y_1 - x_1 + y_2 - x_2 = 3 - 2 = 1$	$B = y_1 - x_1 + y_2 - x_2 = 3 - 2 = 1$

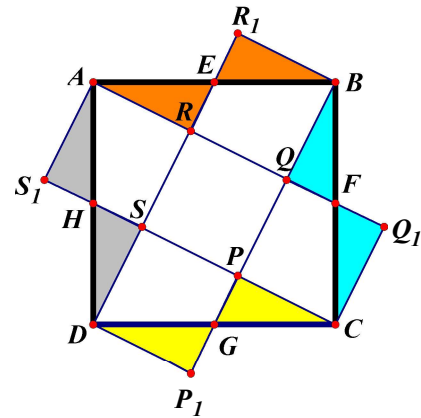
**G2.3** 若  $Q = a^b - b^a$  為正整數，求  $Q$  的最小值。If  $Q = a^b - b^a$  is a positive integer, determine the least value of  $Q$ .

設 $a = 2, b = 1$	Let $a = 2, b = 1$
$Q = 2^1 - 1^2 = 1$	$Q = 2^1 - 1^2 = 1$
$Q$ 的最小值為 $1$ 。	The least value of $Q$ is $1$ .

**G2.4** 在正方形  $ABCD$  中， $E$ 、 $F$ 、 $G$  和  $H$  分別是  $AB$ 、 $BC$ 、 $CD$  和  $AD$  的中點。  $DE$  分別與  $AF$  和  $CH$  相交於點  $R$  和  $S$ 。  $BG$  分別與  $AF$  和  $CH$  相交於點  $Q$  和  $P$ 。 若  $U$  是正方形  $ABCD$  的面積，而  $V$  是四邊形  $PQRS$  的面積，求  $W = \frac{U}{V}$  的值。

In square  $ABCD$ ,  $E, F, G, H$  are the mid-points of  $AB, BC, CD$  and  $AD$  respectively.  $DE$  intersects with  $AF$  and  $CH$  at  $R$  and  $S$  respectively. Moreover,  $BG$  intersects with  $AF$  and  $CH$  at  $Q$  and  $P$  respectively. If  $U$  is the area of square  $ABCD$  and  $V$  is the area of the quadrilateral  $PQRS$ ,

determine the value of  $W = \frac{U}{V}$ .



將  $\triangle CPG$  繞  $G$  旋轉  $180^\circ$  至  $\triangle DP_1G$ 。  
 將  $\triangle BQF$  繞  $F$  旋轉  $180^\circ$  至  $\triangle CQ_1F$ 。  
 將  $\triangle ARE$  繞  $E$  旋轉  $180^\circ$  至  $\triangle BR_1E$ 。  
 將  $\triangle DSH$  繞  $H$  旋轉  $180^\circ$  至  $\triangle AS_1H$ 。  
 $AE = EB = BF = FC = CG = GD = DH = HA$   
 $\angle ABF = \angle BCG = \angle CDH = \angle DAE = 90^\circ$   
 $\triangle ABF \cong \triangle BCG \cong \triangle CDH \cong \triangle DAE$  (S.A.S.)  
 $\angle PCG = \angle P_1DG = \angle QBF = \angle Q_1CF$   
 $= \angle RAE = \angle R_1BE = \angle SDH = \angle S_1AH$   
 $\angle CGP = \angle DGP_1 = \angle BFQ = \angle CFQ_1$   
 $= \angle AER = \angle BER_1 = \angle DHS = \angle AHS_1$   
 $\triangle ARE \cong \triangle BR_1E \cong \triangle BQF \cong \triangle CQ_1F$   
 $\cong \triangle CPG \cong \triangle DP_1G \cong \triangle DSH \cong \triangle AS_1H$  (A.S.A.)  
 $AS_1 = DS = DP_1 = CP = CQ_1 = BQ = BR_1 = AR$   
 在  $\triangle ARE$  中， $\angle ARE = 180^\circ - \angle RAE - \angle REA$   
 $= 180^\circ - \angle RAE - \angle AFB$   
 $= 90^\circ$   
 相似地， $\angle BR_1E = \angle BQF = \angle CQ_1F$   
 $= \angle CPG = \angle DP_1G = \angle DSH = \angle AS_1H = 90^\circ$   
 $\therefore PQRS, ARSS_1, BQRR_1, CPQQ_1$  及  $DSPP_1$  為全等的正方形而這五個正方形的面積之和為大正方形  $ABCD$  的面積。

$$W = \frac{U}{V} = 5$$

Rotate  $\triangle CPG$  about  $G$  through  $180^\circ$  to  $\triangle DP_1G$ .  
 Rotate  $\triangle BQF$  about  $F$  through  $180^\circ$  to  $\triangle CQ_1F$ .  
 Rotate  $\triangle ARE$  about  $E$  through  $180^\circ$  to  $\triangle BR_1E$ .  
 Rotate  $\triangle DSH$  about  $H$  through  $180^\circ$  to  $\triangle AS_1H$ .  
 $AE = EB = BF = FC = CG = GD = DH = HA$   
 $\angle ABF = \angle BCG = \angle CDH = \angle DAE = 90^\circ$   
 $\triangle ABF \cong \triangle BCG \cong \triangle CDH \cong \triangle DAE$  (S.A.S.)  
 $\angle PCG = \angle P_1DG = \angle QBF = \angle Q_1CF$   
 $= \angle RAE = \angle R_1BE = \angle SDH = \angle S_1AH$   
 $\angle CGP = \angle DGP_1 = \angle BFQ = \angle CFQ_1$   
 $= \angle AER = \angle BER_1 = \angle DHS = \angle AHS_1$   
 $\triangle ARE \cong \triangle BR_1E \cong \triangle BQF \cong \triangle CQ_1F$   
 $\cong \triangle CPG \cong \triangle DP_1G \cong \triangle DSH \cong \triangle AS_1H$  (A.S.A.)  
 $AS_1 = DS = DP_1 = CP = CQ_1 = BQ = BR_1 = AR$   
 In  $\triangle ARE$ ,  $\angle ARE = 180^\circ - \angle RAE - \angle REA$   
 $= 180^\circ - \angle RAE - \angle AFB$   
 $= 90^\circ$

Similarly,  $\angle BR_1E = \angle BQF = \angle CQ_1F$   
 $= \angle CPG = \angle DP_1G = \angle DSH = \angle AS_1H = 90^\circ$   
 $\therefore PQRS, ARSS_1, BQRR_1, CPQQ_1$  and  $DSPP_1$  are identical squares and the sum of areas of these five squares is equal to that of the larger square  $ABCD$ .

$$W = \frac{U}{V} = 5$$

### Group Event 3

**G3.1** 若  $\sqrt{32 \times 81 \times 343} = b\sqrt{a}$ ，其中  $a$  和  $b$  是正整數，求  $a$  的最小值。

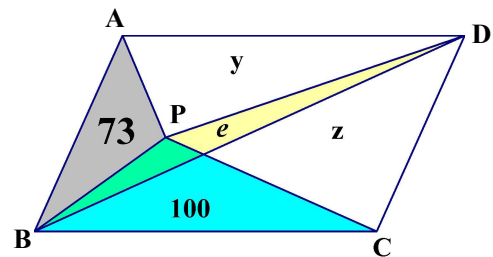
If  $\sqrt{32 \times 81 \times 343} = b\sqrt{a}$ , where  $a$  and  $b$  are positive integers, determine the least value of  $a$ .

**Reference: 2014 FI2.3**

$\sqrt{32 \times 81 \times 343} = b\sqrt{a}$	$\sqrt{32 \times 81 \times 343} = b\sqrt{a}$
$\sqrt{16 \times 2 \times 81 \times 49 \times 7} = b\sqrt{a}$	$\sqrt{16 \times 2 \times 81 \times 49 \times 7} = b\sqrt{a}$
$4 \times 9 \times 7 \sqrt{2 \times 7} = b\sqrt{a}$	$4 \times 9 \times 7 \sqrt{2 \times 7} = b\sqrt{a}$
$a$ 的最小值 = 14。	The least value of $a = 14$ .

**G3.2** 下圖中， $P$  點在平行四邊形  $ABCD$  內。若  $\triangle ABP$ 、 $\triangle BPC$  和  $\triangle BPD$  的面積分別為  $73 \text{ cm}^2$ 、 $100 \text{ cm}^2$  和  $e \text{ cm}^2$ ，求  $e$  的值。

In the diagram below, point  $P$  is inside parallelogram  $ABCD$ . If areas of  $\triangle ABP$ ,  $\triangle BPC$  and  $\triangle BPD$  are  $73 \text{ cm}^2$ ,  $100 \text{ cm}^2$  and  $e \text{ cm}^2$  respectively, determine the value of  $e$ .



**Reference: 2011 FG4.4, 2014 FG3.2**

設 $\triangle APD$ 及 $\triangle CDP$ 的面積分別為 $y \text{ cm}^2$ 及 $z \text{ cm}^2$ 。 $100 + y = 73 + z = 73 + y + e = 100 + z - e$ $e = 27$	Let the areas of $\triangle APD$ and $\triangle CDP$ be $y \text{ cm}^2$ and $z \text{ cm}^2$ respectively. $100 + y = 73 + z = 73 + y + e = 100 + z - e$ $e = 27$
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**G3.3** 在以下的  $3 \times 3$  幻方中，每行、列和兩斜行(對角線)的和相等。如下圖所示，部份數值已經填上。求  $c$  的值。

A  $3 \times 3$  magic square is filled with a number in each square such that the sum of the three numbers in each row, column and the two main diagonals are equal. The partially completed grid is shown below. Determine the value of  $c$ .

$c$	16	20	$c$	16	20
2			2	$x$	$y$
			$z$	$t$	$v$

<p>設其他未填的空格為 <math>x</math>、<math>y</math>、<math>z</math>、<math>t</math> 及 <math>v</math> 如圖所示。設每一行、列和斜行之和為 <math>s</math>。</p> <p><math>s = c + 16 + 20 \dots (1)</math>, <math>s = 2 + x + y \dots (2)</math></p> <p><math>s = c + 2 + z \dots (3)</math>, <math>s = c + x + v \dots (4)</math></p> <p><math>s = z + t + v \dots (5)</math>, <math>s = 16 + x + t \dots (6)</math></p> <p><math>s = 20 + y + v \dots (7)</math>, <math>s = 20 + x + z \dots (8)</math></p> <p>(1) = (4): <math>x + v = 36 \dots (10)</math></p> <p>(2) = (7): <math>x = 18 + v \dots (10)</math></p> <p>代(10)入(9): <math>18 + v + v = 36 \Rightarrow v = 9 \dots (11)</math></p> <p>(1) = (3): <math>z + 2 = 16 + 20</math></p> <p><math>z = 34 \dots (12)</math></p> <p>(2) = (8) 及代 (12): <math>2 + x + y = 20 + x + 34</math></p> <p><math>y = 52 \dots (13)</math></p> <p>(2) = (6) 及代 (13): <math>2 + x + y = 16 + x + t</math></p> <p><math>t = 38 \dots (14)</math></p> <p>(4) = (8) 及代(12), (14): <math>c + x + 38 = 20 + x + 34</math></p> <p><math>c = 16</math></p>	<p>Let the other empty cells be <math>x</math>, <math>y</math>, <math>z</math>, <math>t</math> and <math>v</math> as shown. Let the sum be <math>s</math>.</p> <p><math>s = c + 16 + 20 \dots (1)</math>, <math>s = 2 + x + y \dots (2)</math></p> <p><math>s = c + 2 + z \dots (3)</math>, <math>s = c + x + v \dots (4)</math></p> <p><math>s = z + t + v \dots (5)</math>, <math>s = 16 + x + t \dots (6)</math></p> <p><math>s = 20 + y + v \dots (7)</math>, <math>s = 20 + x + z \dots (8)</math></p> <p>(1) = (4) <math>x + v = 36 \dots (9)</math></p> <p>(2) = (7): <math>x = 18 + v \dots (10)</math></p> <p>Sub. (10) into (9): <math>18 + v + v = 36 \Rightarrow v = 9 \dots (11)</math></p> <p>(1) = (3): <math>z + 2 = 16 + 20</math></p> <p><math>z = 34 \dots (12)</math></p> <p>(2) = (8) and sub. (12): <math>2 + x + y = 20 + x + 34</math></p> <p><math>y = 52 \dots (13)</math></p> <p>(2) = (6) and sub. (13): <math>2 + x + y = 16 + x + t</math></p> <p><math>t = 38 \dots (14)</math></p> <p>(4) = (8), sub. (11), (12): <math>c + x + 9 = 20 + x + 34</math></p> <p><math>c = 45</math></p>
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**G3.4** 若  $X = 2^{2018} + 3^{2018}$  及  $d$  是其個位數字，求  $d$  的值。

If  $X = 2^{2018} + 3^{2018}$  and  $d$  is the units digit, determine the value of  $d$ .

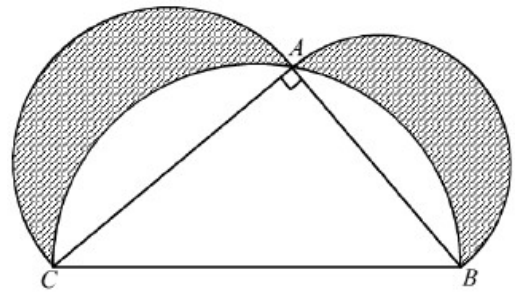
**Reference: 1996 FG9.1**

$2 = 2, 2^2 = 4, 2^3 = 8, 2^4 = 16, 2^5 = 32$ $2^n$ 的個位數字跟以下規律重覆：2、4、8、6。 $2018 = 4 \times 504 + 2$ $2^{2018}$ 的個位數字是4。 $3 = 3, 3^2 = 9, 3^3 = 27, 3^4 = 81$ $3^n$ 的個位數字跟以下規律重覆：3、9、7、1。 $3^{2018}$ 的個位數字是9。 $d = 4 + 9 \pmod{10} = 3$	$2 = 2, 2^2 = 4, 2^3 = 8, 2^4 = 16, 2^5 = 32$ The units digit of $2^n$ repeats in the pattern 2,4,8,6 $2018 = 4 \times 504 + 2$ The units digit of $2^{2018}$ is 4. $3 = 3, 3^2 = 9, 3^3 = 27, 3^4 = 81$ The units digit of $3^n$ repeats in the pattern 3,9,7,1 The units digit of $3^{2018}$ is 9. $d = 4 + 9 \pmod{10} = 3$
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# Group Event 4

**G4.1** 如圖所示， $\triangle ABC$  是一直角三角形，其中  $AC = 8$ ， $BC = 10$ 。以  $AB$ 、 $AC$  和  $BC$  為直徑分別畫了三個半圓。若陰影部分的總面積是  $\alpha$ ，求  $\alpha$  的值。

As shown in the figure,  $\triangle ABC$  is a right-angled triangle with  $AC = 8$  and  $BC = 10$ . Semi-circles are drawn with  $AB$ ,  $AC$  and  $BC$  as diameters. If the total shaded area is  $\alpha$ , determine the value of  $\alpha$ .



**Reference: 1994 HI9, 2009 FG4.2**

$AB^2 + 8^2 = 10^2$ (畢氏定理)	$AB^2 + 8^2 = 10^2$ (Pythagoras' theorem)
$AB = 6$	$AB = 6$
$\alpha = 6 \times 8 \div 2 + \pi(3)^2 + \pi(4)^2 - \pi(5)^2 = 24$	$\alpha = 6 \times 8 \div 2 + \pi(3)^2 + \pi(4)^2 - \pi(5)^2 = 24$

**G4.2** 對所有的正整數  $n$ ，設某一個函數  $F(n)$  有如下定義：

$$F(1) = 0,$$

當  $n \geq 2$ ，

如果  $n$  只能被 2 整除而不能被 3 整除，則  $F(n) = F(n-1) + 2$ ；

如果  $n$  只能被 3 整除而不能被 2 整除，則  $F(n) = F(n-1) + 3$ ；

如果  $n$  既能被 2 整除而又能被 3 整除，則  $F(n) = F(n-1) + 4$ ；

如果  $n$  既不能被 2 整除而又不能被 3 整除，則  $F(n) = F(n-1)$ 。

若  $\beta = F(4000)$ ，求  $\beta$  的值。

For all positive integers  $n$ , suppose there exists a function  $F(n)$  defined as follows:

$$F(1) = 0,$$

for all  $n \geq 2$ ,

$F(n) = F(n-1) + 2$  if 2 divides  $n$  but 3 does not divide  $n$ ;

$F(n) = F(n-1) + 3$  if 3 divides  $n$  but 2 does not divide  $n$ ;

$F(n) = F(n-1) + 4$  if 2 and 3 both divide  $n$ ;

$F(n) = F(n-1)$  if neither 2 nor 3 divides  $n$ .

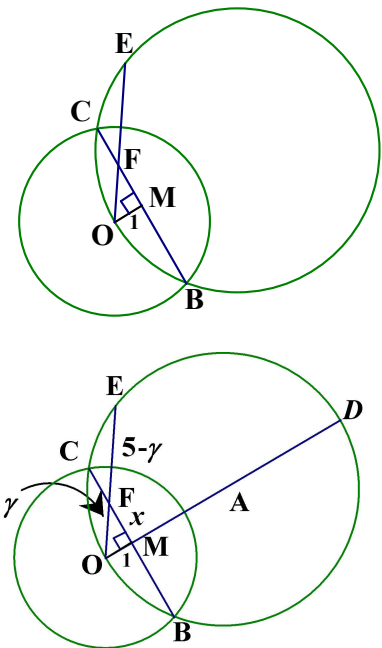
If  $\beta = F(4000)$ , determine the value of  $\beta$ .

$F(n) = \begin{cases} F(n-1)+2 & \text{若 } n=6k+2 \text{ 或 } 6k+4 \\ F(n-1)+3 & \text{若 } n=6k+3 \\ F(n-1)+4 & \text{若 } n=6k \\ F(n-1) & \text{若 } n=6k+1 \text{ 或 } 6k+5 \end{cases}$	$F(n) = \begin{cases} F(n-1)+2 & \text{if } n=6k+2 \text{ or } 6k+4 \\ F(n-1)+3 & \text{if } n=6k+3 \\ F(n-1)+4 & \text{if } n=6k \\ F(n-1) & \text{if } n=6k+1 \text{ or } 6k+5 \end{cases}$
$F(1) = 0, F(2) = 2, F(3) = F(2) + 3 = 5$ $F(4) = F(3) + 2 = 7, F(5) = F(4) = 7$ $F(6) = F(5) + 4 = 11, F(7) = F(6) = 11$ $F(8) = F(7) + 2 = 13, F(9) = F(8) + 3 = 16$ $F(10) = F(9) + 2 = 18, F(11) = F(10) = 18$ $F(12) = F(11) + 4 = 22$	$F(1) = 0, F(2) = 2, F(3) = F(2) + 3 = 5$ $F(4) = F(3) + 2 = 7, F(5) = F(4) = 7$ $F(6) = F(5) + 4 = 11, F(7) = F(6) = 11$ $F(8) = F(7) + 2 = 13, F(9) = F(8) + 3 = 16$ $F(10) = F(9) + 2 = 18, F(11) = F(10) = 18$ $F(12) = F(11) + 4 = 22$
利用數學歸納法，	Inductively,
$F(n) = \begin{cases} 11k & \text{若 } n=6k+1 \\ 11k+2 & \text{若 } n=6k+2 \\ 11k+5 & \text{若 } n=6k+3 \\ 11k+7 & \text{若 } n=6k+4 \text{ 或 } n=6k+5 \\ 11k & \text{若 } n=6k \end{cases}$	$F(n) = \begin{cases} 11k & \text{if } n=6k+1 \\ 11k+2 & \text{if } n=6k+2 \\ 11k+5 & \text{if } n=6k+3 \\ 11k+7 & \text{if } n=6k+4 \text{ or } n=6k+5 \\ 11k & \text{if } n=6k \end{cases}$
$4000 = 6 \times 666 + 4$ $F(4000) = 11 \times 666 + 7 = 7333$	$4000 = 6 \times 666 + 4$ $F(4000) = 11 \times 666 + 7 = 7333$

**G4.3** 如圖所示，兩圓相交於  $B$ 、 $C$  兩點。 $M$  是  $BC$  的中點。 $O$  在大圓上，使得  $OM \perp BC$ 。 $OM=1$ 、 $OC=3$  及  $OE=5$ 。  
若  $\gamma = OF$ ，求  $\gamma$  的值。

Two circles intersect at  $B$ ,  $C$  as shown in the figure.  $M$  is the mid-point of  $BC$ .  $O$  is a point on the larger circle, so that  $OM \perp BC$ .  $OM=1$ ,  $OC=3$  and  $OE=5$ .

If  $\gamma = OF$ , determine the value of  $\gamma$ .



設  $A$  為大圓的圓心。

連接並延長  $OA$  使其再交大圓於  $D$ 。

$AO \perp BC$  (圓心至弦綫的中點垂直於弦)

$A$ 、 $M$ 、 $O$  共綫 (普萊費爾公理)

在  $\triangle CMO$  中， $OC=3$ ， $OM=1$ ， $OM \perp BC$

$1^2 + CM^2 = 3^2$  (畢氏定理)

$CM = 2\sqrt{2} = BM$

在  $\triangle OFM$  中，設  $MF = x$ ， $\gamma^2 - x^2 = 1$  (畢氏定理)

$OF = \gamma$ ， $EF = 5 - x$ ， $CF = CM - MF = 2\sqrt{2} - x$

$BF = BM + MF = 2\sqrt{2} + x$

由相交弦定理， $OF \times EF = BF \times CF$

$\gamma(5 - \gamma) = (2\sqrt{2} - x)(2\sqrt{2} + x)$

$5\gamma - \gamma^2 = 8 - x^2$

$5\gamma = 8 + (\gamma^2 - x^2)$

$5\gamma = 8 + 1 = 9$

$\gamma = \frac{9}{5} = 1.8$

Let  $A$  be the centre of the larger circle.

Join and produce  $OA$  to cut the circle again at  $D$ .

$AO \perp BC$  (line joining centre to mid-pt. of chord  $\perp$  chord)

$A$ ,  $M$ ,  $O$  are collinear (Playfair's axiom)

In  $\triangle CMO$ ,  $OC=3$ ,  $OM=1$ ,  $OM \perp BC$

$1^2 + CM^2 = 3^2$  (Pythagoras' theorem)

$CM = 2\sqrt{2} = BM$

In  $\triangle OFM$ , let  $MF = x$ ,  $\gamma^2 - x^2 = 1$  (Pythagoras' thm)

$OF = \gamma$ ,  $EF = 5 - x$ ,  $CF = CM - MF = 2\sqrt{2} - x$

$BF = BM + MF = 2\sqrt{2} + x$

By intersecting chords theorem,  $OF \times EF = BF \times CF$

$\gamma(5 - \gamma) = (2\sqrt{2} - x)(2\sqrt{2} + x)$

$5\gamma - \gamma^2 = 8 - x^2$

$5\gamma = 8 + (\gamma^2 - x^2)$

$5\gamma = 8 + 1 = 9$

$\gamma = \frac{9}{5} = 1.8$

**G4.4** 若  $f(x) = \left(x + \frac{1}{2000}\right) \times \left(x + \frac{1}{2001}\right) \times \cdots \times \left(x + \frac{1}{2019}\right)$  以及  $\delta = f(1) - 1$ ，求  $\delta$  的值。

If  $f(x) = \left(x + \frac{1}{2000}\right) \times \left(x + \frac{1}{2001}\right) \times \cdots \times \left(x + \frac{1}{2019}\right)$  and  $\delta = f(1) - 1$ ,

determine the value of  $\delta$ .

$\delta = f(1) - 1 = \left(1 + \frac{1}{2000}\right) \times \left(1 + \frac{1}{2001}\right) \times \cdots \times \left(1 + \frac{1}{2019}\right) - 1$

$= \frac{2001}{2000} \times \frac{2002}{2001} \times \cdots \times \frac{2020}{2019} - 1 = \frac{2020}{2000} - 1$

$= 1.01 - 1 = 0.01$