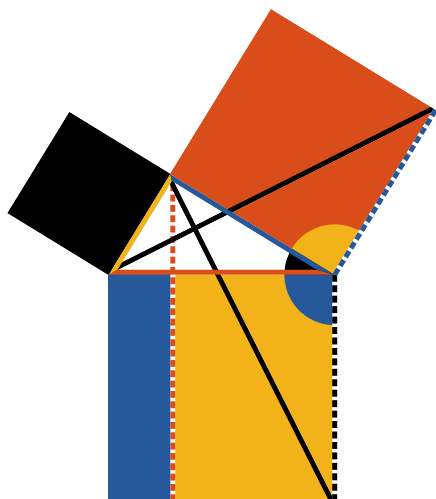


LOS PRIMEROS SEIS LIBROS DE LOS ELEMENTOS DE EUCLIDES

EN EL QUE SE UTILIZAN DIAGRAMAS Y
SÍMBOLOS COLOREADOS EN LUGAR DE
LETRAS PARA FACILITAR EL APRENDIZAJE

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github.com/jemmybutton

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Introducción

LAS artes y ciencias se han vuelto tan extensas, que facilitar su adquisición es de tanta importancia como extender sus límites. La ilustración, si no acorta el tiempo de estudio, al menos lo hará más agradable. Este trabajo tiene un objetivo mayor que la mera ilustración; no introducimos colores con el propósito de entretener, o para entretener *con ciertas combinaciones de matiz y forma*, pero para ayudar a la mente en sus investigaciones de la verdad, para aumentar las facilidades de introducción y para difundir el conocimiento permanente. Si quisiéramos autoridades para probar la importancia y utilidad de la geometría, podríamos citar a todos los filósofos desde el día de Platón. Entre los griegos, en la antigüedad, como en la escuela de Pestalozzi y otros en tiempos recientes, la geometría fue adoptada como el mejor gimnasio de la mente. De hecho, los Elementos de Euclides se han convertido, por consentimiento común, en la base de la ciencia matemática en todo el mundo civilizado. Pero esto no parecerá extraordinario, si consideramos que esta ciencia sublime no solo está mejor calculada que cualquier otra para despertar el espíritu de investigación, elevar la mente y fortalecer las facultades de razonamiento, sino que también constituye la mejor introducción a la mayoría de las vocaciones útiles e importantes de la vida humana. La aritmética, la topografía, la hidrostática, la neumática, la óptica, la astronomía física, etc. dependen todas de las proposiciones de la geometría.

Mucho sin embargo depende de la primera comu-

nicación de cualquier ciencia a un alumno, aunque los métodos mejores y más fáciles rara vez se adoptan. Se presentan proposiciones a un estudiante, a quien, aunque tenga una comprensión suficiente, se le dice tan poco sobre ellas al entrar en el umbral mismo de la ciencia, que se le da una predisposición muy desfavorable para su futuro estudio de este tema delicioso; o “las formalidades y parafernalia del rigor se presentan de manera tan ostentosa, que casi ocultan la realidad. Las repeticiones interminables y desconcertantes, que no confieren mayor exactitud al razonamiento, hacen que las demostraciones sean complejas y oscuras, y ocultan a la vista del estudiante la sucesión de la evidencia.” Así se crea una aversión en la mente del alumno, y un tema tan calculado para mejorar las facultades de razonamiento y dar el hábito de pensar con atención se degrada por un curso de instrucción seco y rígido en un ejercicio poco interesante de la memoria. Despertar la curiosidad y despertar las facultades letárgicas y latentes de las mentes jóvenes debería ser el objetivo de todo maestro; pero donde faltan ejemplos de excelencia, los intentos de alcanzarla son pocos, mientras que la eminencia excita la atención y produce imitación. El objetivo de esta obra es introducir un método de enseñanza de la geometría que ha sido muy aprobado por muchos hombres de ciencia en este país, así como en Francia y América. El plan aquí adoptado apela fuertemente al ojo, el más sensible y el más completo de nuestros órganos externos, y su preeminencia para grabar su tema en la mente está respaldada por el axioma incontrovertible expresado en las conocidas palabras de Horacio:—

*Segnius irritant animos demissa per aurem
Quam quae sunt oculis subjecta fidelibus*

La impresión que llega al oído es más débil
que la que transmite el ojo fiel.

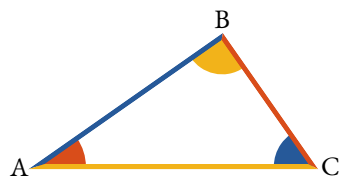
Todo el lenguaje consiste en signos representativos, y

los mejores signos son aquellos que cumplen sus propósitos con la mayor precisión y rapidez. Tales, para todos los propósitos comunes, son los signos audibles llamados palabras, que todavía se consideran audibles, ya sea que se dirijan inmediatamente al oído o a través del medio de las letras al ojo. Los diagramas geométricos no son signos, sino los materiales de la ciencia geométrica, cuyo objeto es mostrar las cantidades relativas de sus partes mediante un proceso de razonamiento llamado Demostración. Este razonamiento se ha llevado a cabo generalmente con palabras, letras y diagramas negros o incoloros; pero como el uso de símbolos, signos y diagramas coloreados en las artes y ciencias lineales hace que el proceso de razonamiento sea más preciso y la adquisición más rápida, se han adoptado en este caso en consecuencia.

La expedición de este modo tan atractivo de comunicar conocimientos es tal, que los Elementos de Euclides pueden adquirirse en menos de un tercio del tiempo habitualmente empleado, y la retención por la memoria es mucho más duradera; estos hechos han sido comprobados por numerosos experimentos realizados por el inventor y varios otros que han adoptado sus planes. Los detalles de los cuales son pocos y obvios; las letras anexas a puntos, líneas u otras partes de un diagrama son en realidad meros nombres arbitrarios y los representan en la demostración; en lugar de estos, las partes, al estar coloreadas de manera diferente, se nombran a sí mismas, ya que sus formas en colores correspondientes las representan en la demostración.

Para dar una mejor idea de este sistema y de las ventajas que se obtienen con su adopción, tomemos un triángulo rectángulo y expresemos algunas de sus propiedades tanto con colores como con el método generalmente empleado.

Algunas de las propiedades del triángulo rectángulo ABC, expresadas por el método generalmente empleado:



1. El ángulo BAC, junto con los ángulos BCA y ABC son iguales a dos ángulos rectos, o al doble del ángulo ABC.
2. El ángulo CAB sumado al ángulo ACB será igual al ángulo ABC.
3. El ángulo ABC es mayor que cualquiera de los ángulos BAC o BCA.
4. El ángulo BCA o el ángulo CAB es menor que el ángulo ABC.
5. Si del ángulo ABC se toma el ángulo BAC, el residuo será igual al ángulo ACB.
6. The square of AC is equal to the sum of the squares of AB and BC.

Las mismas propiedades expresadas coloreando las diferentes partes:

$$1. \quad \triangle_{\text{rojo}} + \triangle_{\text{amarillo}} + \triangle_{\text{azul}} = 2 \triangle_{\text{amarillo}} = \text{semicírculo}.$$

Es decir, el ángulo rojo sumado al ángulo amarillo sumado al ángulo azul, es igual al doble del ángulo amarillo, igual a dos ángulos rectos.

$$2. \quad \triangle_{\text{rojo}} + \triangle_{\text{azul}} = \triangle_{\text{amarillo}}.$$

O en otras palabras, el ángulo rojo sumado al ángulo azul, es igual al ángulo amarillo.

$$3. \quad \triangle_{\text{amarillo}} > \triangle_{\text{rojo}} \text{ or } > \triangle_{\text{azul}}.$$

El ángulo amarillo es mayor que cualquiera de los ángulos rojo o azul.

$$4. \quad \triangle_{\text{rojo}} \text{ or } \triangle_{\text{azul}} < \triangle_{\text{amarillo}}.$$

El ángulo rojo o azul es menor que el ángulo amarillo.

5.  -  = .

En otros términos, el ángulo amarillo menos el ángulo azul es igual al ángulo rojo.

6.  ² =  ² + .

Es decir, el cuadrado de la línea amarilla es igual a la suma de los cuadrados de las líneas azul y roja.

En las demostraciones orales obtenemos con los colores esta importante ventaja: el ojo y el oído pueden ser atendidos al mismo tiempo, por lo que para enseñar geometría y otras artes y ciencias lineales en clases, el sistema es el mejor que se ha propuesto jamás, esto es evidente por los ejemplos dados.

De donde se deduce que una referencia del texto al diagrama es más rápida y segura, al dar las formas y colores de las partes, o al nombrar las partes y sus colores, que al nombrar las partes y las letras en el diagrama. Además de la simplicidad superior, este sistema también se destaca por su concentración y excluye por completo la práctica perjudicial, aunque frecuente, de permitir que el alumno memorice la demostración; hasta que la razón, el hecho y la prueba solamente dejen impresiones en el entendimiento.

De nuevo, al dar una conferencia sobre los principios o propiedades de las figuras, si mencionamos el color de la parte o partes a las que se hace referencia, como al decir, el ángulo rojo, la línea azul o líneas, etc., la parte o partes así nombradas serán vistas inmediatamente por toda la clase al mismo instante; no así si decimos el ángulo ABC, el triángulo PFQ, la figura EG Kt, y así sucesivamente; porque las letras deben trazarse una por una antes de que los estudiantes organicen en sus mentes la magnitud particular a la que se refieren, lo que a menudo ocasiona confusión y error, así como pérdida de tiempo. Además, si las partes que se dan como iguales tienen los mismos colores en cualquier diagrama, la mente no se desviará del objeto que tiene ante sí; es decir, tal disposición presenta

una demostración ocular de las partes que deben probarse como iguales, y el alumno retiene los datos durante todo el razonamiento. Pero cualesquiera que sean las ventajas del plan actual, si no se sustituye, siempre puede ser un poderoso auxiliar de los otros métodos, con el propósito de introducción, o de una reminiscencia más rápida, o de una retención más permanente por la memoria.

La experiencia de todos los que han formado sistemas para impresionar hechos en la comprensión, concuerda en probar que las representaciones coloreadas, como imágenes, grabados, diagramas, etc. son más fáciles de fijar en la mente que las meras oraciones sin ninguna peculiaridad. Curioso como pueda parecer, los poetas parecen ser más conscientes de este hecho que los matemáticos; muchos poetas modernos aluden a este sistema visible de comunicar conocimiento, uno de ellos se ha expresado así:

Los sonidos que se dirigen al oído se pierden y mueren
 En una hora corta, pero estos que golpean el ojo,
 Viven mucho en la mente, la vista fiel
 Graba el conocimiento con un rayo de luz.

Esto quizás pueda considerarse la única mejora que ha recibido la geometría plana desde los días de Euclides, y si hubo algún geómetra de renombre antes de esa época, el éxito de Euclides ha eclipsado por completo su memoria, e incluso ha hecho que todas las cosas buenas de ese tipo se le atribuyan a él; como *Æsop* entre los escritores de fábulas. También cabe señalar que, dado que los diagramas tangibles proporcionan el único medio a través del cual la geometría y otras artes lineales pueden enseñarse a los ciegos, el sistema visible es igualmente adecuado para las exigencias de los sordomudos.

Se debe tener cuidado de mostrar que el color no tiene nada que ver con las líneas, ángulos o magnitudes, excepto meramente para nombrarlos. Una línea matemática, que es longitud sin anchura, no puede poseer color, sin

embargo, la unión de dos colores en el mismo plano da una buena idea de lo que se entiende por una línea matemática; recordemos que estamos hablando familiarmente, dicha unión debe entenderse y no el color, cuando decimos la línea negra, la línea roja o las líneas, etc.

Los colores y los diagramas coloreados pueden parecer al principio un método torpe para transmitir nociones adecuadas de las propiedades y partes de las figuras y magnitudes matemáticas, sin embargo, se encontrarán que ofrecen un medio más refinado y extenso que cualquiera que se haya propuesto hasta ahora.

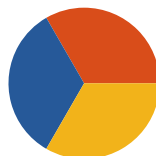
Aquí definiremos un punto, una línea y una superficie, y demostraremos una proposición para mostrar la verdad de esta afirmación.

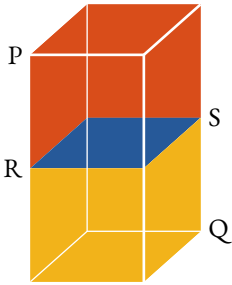
Un punto es aquello que tiene posición, pero no magnitud; o un punto es solo posición, abstraído de la consideración de longitud, anchura y grosor. Quizás la siguiente descripción esté mejor calculada para explicar la naturaleza del punto matemático a aquellos que no han adquirido la idea, que la definición anterior, aunque especiosa.

Que tres colores se encuentren y cubran una porción del papel, donde se encuentran no es azul, ni es amarillo, ni es rojo, ya que no ocupa ninguna porción del plano, porque si lo hiciera, pertenecería a la parte azul, roja o amarilla; sin embargo, existe y tiene posición sin magnitud, de modo que con un poco de reflexión, esta unión de tres colores en un plano da una buena idea de un punto matemático.

Una línea es longitud sin anchura. Con la ayuda de colores, casi de la misma manera que antes, se puede dar así una idea de una línea:—

Que dos colores se encuentren y cubran una porción del papel; donde se encuentran no es rojo, ni es azul; por lo tanto, la unión no ocupa ninguna porción del plano, y por lo tanto no puede tener anchura, sino solo longitud: de lo que podemos formarnos fácilmente una idea de lo





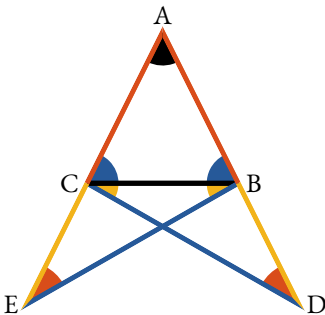
que se entiende por una línea matemática. A efectos de ilustración, un color que difiera del color del papel, o del plano sobre el que está dibujado, habría sido suficiente; de ahí en adelante, si decimos la línea roja, la línea azul o las líneas, etc. se entiende que son las uniones con el plano sobre el que están dibujadas.

Una superficie es aquello que tiene longitud y anchura sin grosor.














Cuando consideramos un cuerpo sólido (PQ), percibimos de inmediato que tiene tres dimensiones, a saber: longitud, anchura y grosor; supongamos que una parte de este sólido (PS) es roja, y la otra parte (QR) amarilla, y que los colores son distintos sin mezclarse, la superficie azul (RS) que separa estas partes, o que es lo mismo, que divide el sólido sin pérdida de material, debe carecer de grosor, y solo posee longitud y anchura; esto aparece claramente por un razonamiento similar al que se acaba de emplear para definir, o más bien describir, un punto y una línea.

La proposición que hemos seleccionado para elucidar la manera en que se aplican los principios, es la quinta del primer Libro.

En un triángulo isósceles ABC, los ángulos internos en la base ABC, ACB son iguales, y cuando los lados AB, AC se prolongan, los ángulos externos en la base BCE, CBD también son iguales.



Produce  y ,
haz  = , dibuja  y .

En  y 
tenemos  = ,
 común y  =  :
 \therefore  = ,  = 
y  =  (prop. I.4).

De nuevo en  y ,

$$\begin{array}{c}
 \text{---} = \text{---}, \triangle = \triangle \\
 y \text{ ---} = \text{---}; \\
 \therefore \triangle = \triangle y \triangle = \triangle \text{ (prop. I.4)} \\
 \text{Pero } \triangle = \triangle, \therefore \triangle = \triangle.
 \end{array}$$

Q. E. D.

Anexando las letras al diagrama.

Sean los lados iguales AB y AC producidos a través de los extremos BC, del tercer lado, y en la parte producida BD de cualquiera, sea asumido cualquier punto D, y del otro sea cortado AE igual a AD (prop. I.3). Sean los puntos E y D, así tomados en los lados producidos, conectados por líneas rectas DC y BE con los extremos alternos del tercer lado del triángulo.

En los triángulos DAC y EAB los lados DA y AC son respectivamente iguales a EA y AB, y el ángulo incluido A es común a ambos triángulos. Por lo tanto (prop. I.4) la línea DC es igual a BE, el ángulo ADC al ángulo AEB, y el ángulo ACD al ángulo ABE; si de las líneas iguales AD y AE se toman los lados iguales AB y AC, los residuos BD y CE serán iguales. Por lo tanto en los triángulos BDC y CEB, los lados BD y DC son respectivamente iguales a CE y EB, y los ángulos D y E incluidos por esos lados también son iguales. Por lo tanto (prop. I.4) los ángulos DBC y ECB, que son los incluidos por el tercer lado BC y las producciones de los lados iguales AB y AC son iguales. También los ángulos DCB y ECB son iguales si esos iguales se toman de los ángulos DCA y EBA antes probados iguales, los residuos, que son los ángulos ABC y ACB opuestos a los lados iguales, serán iguales.

Por lo tanto en un triángulo isósceles, etc.

Q. E. D.

Nuestro objeto en este lugar es introducir el sistema en lugar de enseñar cualquier conjunto particular de proposiciones, por lo tanto hemos seleccionado las anteriores

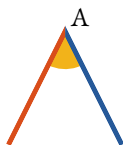
del curso regular. Para escuelas y otros lugares públicos de instrucción, las tizas teñidas servirán para describir los diagramas, etc. para uso privado los lápices de colores resultarán muy convenientes.

Estamos felices de encontrar que los Elementos de las Matemáticas ahora forman una parte considerable de toda educación femenina sólida, por lo tanto llamamos la atención de aquellos interesados o comprometidos en la educación de las damas a este modo muy atractivo de comunicar conocimiento, y al trabajo sucesivo para su futuro desarrollo.

Nosotros concluiremos por el momento observando, ya que los sentidos de la vista y el oído pueden ser tan fuertemente e instantáneamente abordados por igual con mil como con uno, *el millón* podría ser enseñado geometría y otras ramas de las matemáticas con gran facilidad, esto avanzaría el propósito de la educación más que cualquier cosa *podría* ser nombrada, porque enseñaría a la gente cómo pensar, y no qué pensar; es en este particular donde se origina el gran error de la educación.

Elucidaciones

La geometría tiene como objetos principales la exposición y explicación de las propiedades de la *figura*, y la figura se define como la relación que existe entre los límites del espacio. El espacio o la magnitud es de tres clases, *lineal*, *superficial* y *sólido*.



Los ángulos podrían considerarse apropiadamente como una cuarta especie de magnitud. La magnitud angular evidentemente consta de partes, y por lo tanto debe admitirse que es una especie de cantidad. El estudiante no debe suponer que la magnitud de un ángulo es afectada por la longitud de las líneas rectas que lo incluyen y de cuya divergencia mutua es la medida. El *vértice* de un

ángulo es el punto donde se encuentran los *lados* de las *patas* del ángulo, como A.

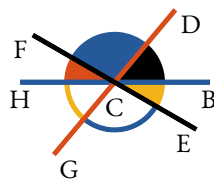
Un ángulo se designa a menudo por una sola letra cuando sus lados son las únicas líneas que se encuentran en su vértice. Así, las líneas roja y azul forman el ángulo amarillo, que en otros sistemas se llamaría ángulo A. Pero cuando más de dos líneas se encuentran en el mismo punto, era necesario por métodos anteriores, para evitar confusiones, emplear tres letras para designar un ángulo alrededor de ese punto, la letra que marcaba el vértice del ángulo se colocaba siempre en el medio. Así, las líneas negra y roja que se encuentran en C, forman el ángulo azul, y ha sido usualmente denominado el ángulo FCD o DCF. Las líneas FC y CD son los lados del ángulo; el punto C es su vértice. De manera similar, el ángulo negro se designaría el ángulo DCB o BCD. Los ángulos rojo y azul sumados, o el ángulo HCF sumado a FCD, forman el ángulo HCD; y así de otros ángulos.

Cuando los lados de un ángulo se producen o prolongan más allá de su vértice, los ángulos formados por ellos en ambos lados del vértice se dicen que son *opuestos por el vértice* entre sí: así, los ángulos rojo y amarillo se dicen que son ángulos opuestos por el vértice.

La *superposición* es el proceso por el cual una magnitud puede concebirse colocada sobre otra, de modo que la cubra exactamente, o de modo que cada parte de cada una coincida exactamente.

Una línea se dice que es *producida*, cuando es extendida, prolongada, o tiene su longitud aumentada, y el aumento de longitud que recibe se llama *parte producida*, o su *producción*.

La longitud total de la línea o líneas que encierran una figura, se llama su *perímetro*. Los primeros seis libros de Euclides tratan solo de figuras planas. Una línea trazada desde el centro de un círculo hasta su circunferencia, se llama *radio*. El lado de un triángulo rectángulo, que es opuesto al án-



gulo recto, se llama *hipotenusa*. Un oblongo se define en el segundo libro, y se llama *rectángulo*. Se supone que todas las líneas consideradas en los primeros seis libros de los Elementos están en el mismo plano.

La *regla* y el *compás* son los únicos instrumentos cuyo uso está permitido en Euclides, o en la Geometría plana. Declarar esta restricción es el objeto de los *postulados*.

Los *axiomas* de la geometría son ciertas proposiciones generales, cuya verdad se toma como autoevidente e incapaz de ser establecida por demostración.

Las *proposiciones* son aquellos resultados que se obtienen en geometría por un proceso de razonamiento. Hay dos especies de proposiciones en geometría, *problemas* y *teoremas*.

Un *problema* es una proposición en la que se propone hacer algo; como una línea que se va a trazar bajo algunas condiciones dadas, un círculo que se va a describir, alguna figura que se va a construir, etc.

La *solución* del problema consiste en mostrar cómo se puede hacer la cosa requerida con la ayuda de la regla o straight-edge y el compás.

La *demostración* consiste en probar que el proceso indicado en la solución alcanza el fin requerido.

Un *teorema* es una proposición en la que se afirma la verdad de algún principio. Este principio debe deducirse de los axiomas y definiciones, u otras verdades previamente y de forma independiente establecidas. Mostrar esto es el objeto de la demostración.

Un *problema* es análogo a un postulado.

Un *teorema* se asemeja a un axioma.

Un *postulado* es un problema, cuya solución se asume.

Un *axioma* es un teorema, cuya verdad se concede sin demostración.

Un *corolario* es una inferencia deducida inmediatamente de una proposición.

Un *escolio* es una nota u observación sobre una

proposición que no contiene una inferencia de importancia suficiente para merecer el nombre de *corolario*.

Un *lema* es una proposición introducida meramente con el propósito de establecer una proposición más importante.

Símbolos y abreviaturas

\therefore expresa la palabra *por lo tanto*.

\because expresa la palabra *porque*.

$=$ expresa la palabra *igual*. Este signo de igualdad puede leerse *igual a*, o *es igual a*, o *son iguales a*; pero la discrepancia con respecto a la introducción de los verbos auxiliares *es*, *son*, etc. no puede afectar el rigor geométrico.

\neq significa lo mismo que si se escribieran las palabras '*not equal*'.

$>$ significa *mayor que*.

$<$ significa *menor que*.

\nlessgtr significa *no mayor que*.

\nlessgtr significa *no menor que*.

$+$ se lee *más*, el signo de adición; cuando se interpone entre dos o más magnitudes, significa su suma.

$-$ se lee *menos*, significa la resta; y cuando se coloca entre dos cantidades, denota que la última se toma de la primera.

\times este signo expresa el producto de dos o más números cuando se coloca entre ellos en aritmética y álgebra; pero en geometría se usa generalmente para expresar un *rectángulo*, cuando se coloca entre "dos líneas rectas que contienen uno de sus ángulos rectos." Un *rectángulo* también puede representarse colocando un punto entre dos de sus lados contiguos.

$::::$ expresa una *analogía* o *proporción*; así, si A, B, C y D representan cuatro magnitudes, y A tiene con B la misma razón que C tiene con D, la proporción se escribe brevemente así

$$A : B :: C : D, A : B = C : D, \text{ or } \frac{A}{B} = \frac{C}{D}.$$

Esta igualdad o semejanza de razón se lee,

como A es a B, así es C a D;

o A es a B, como C es a D.

\parallel significa *paralelo a*.

\perp significa *perpendicular a*.

\triangle significa *ángulo*.

\curvearrowright significa *ángulo recto*.

\bigcirc significa *dos ángulos rectos*.

\blacktriangleup or \blacktriangleright briefly designates a *punto*.

The square described on a line is concisely written thus, —^2 .

In the same manner twice the square of, is expressed by $2 \cdot \text{—}^2$.

def. significa *definición*.

post. significa *postulado*.

ax. significa *axioma*.

hyp. significa *hipótesis*. Puede ser necesario aquí señalar que *hipótesis* es la condición asumida o dada por sentada.

Así, la hipótesis de la proposición dada en la Introducción, es que el triángulo es isósceles, o que sus lados son iguales.

const. significa *construcción*. La *construcción* es el cambio realizado en la figura original, dibujando líneas, haciendo ángulos, describiendo círculos, etc. para adaptarla al argumento de la demostración o a la solución del problema. Las condiciones bajo las cuales se realizan estos cambios, son tan indiscutibles como las contenidas en la hipótesis. Por ejemplo, si hacemos un ángulo igual a un ángulo dado, estos dos ángulos son iguales por construcción.

Q. E. D. significa *Quod erat demonstrandum*. Lo que se quería demostrar.



Book I

Definiciones

I.1

Un *punto* es el que no tiene partes.

I.2

Una *línea* es longitud sin ancho.

I.3

Los extremos de una línea son puntos.

I.4

Una línea recta o recta es la que se encuentra uniformemente entre sus extremos.

I.5

Una superficie es aquella que sólo tiene longitud y ancho.

I.6

Los extremos de una superficie son líneas.

I.7

Una superficie plana es la que se encuentra uniformemente entre sus extremos.

I.8

Un ángulo plano es la inclinación de dos líneas entre sí, que se encuentran en un plano, pero no están en la misma dirección.



I.9

Un ángulo rectilíneo plano es la inclinación de dos líneas rectas entre sí, que se encuentran, pero no están en la misma línea recta.



I.10

Cuando una línea recta parada sobre otra línea recta hace iguales los ángulos adyacentes, cada uno de estos ángulos es llamado *ángulo recto*, y se dice que cada una de estas líneas es *perpendicular* a la otra.



I.11

Un ángulo obtuso es un ángulo mayor que un ángulo recto.



I.12

Un ángulo agudo es menor que un ángulo recto.

I.13

Un borde o límite es el extremo de cualquier cosa.

I.14

Una figura es una superficie encerrada en todos los lados por una línea o líneas.



I.15

Un es una figura plana, delimitada por una línea continua, llamada *circunferencia* o *periferia*; y tiene un cierto punto dentro de él, desde el cual todas las líneas rectas dibujadas a su circunferencia son iguales.



I.16

Este punto (desde el cual se dibujan las líneas iguales) se llama el *centro del círculo*.

I.17

El es una línea recta dibujada a través del centro, terminada en ambos sentidos en la circunferencia.



I.18

Un semicírculo es la figura contenida por el diámetro, y la parte del círculo cortada por el diámetro.



I.19

Un segmento circular es una figura contenida por una línea recta y la parte de la circunferencia que corta.



I.20

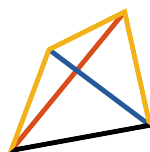
Una figura contenida solo por líneas rectas, se llama figura rectilínea.

I.21

Un triángulo es una figura rectilínea contenida por tres lados.

I.22

Una figura cuadrilátera es aquella que está limitada por cuatro lados. Las líneas rectas ——— y ——— que conectan los vértices de los ángulos opuestos de una figura cuadrilátera, son denominadas sus diagonales.



I.23

Un polígono es una figura rectilínea delimitada por más de cuatro lados.

I.24

Un polígono es una figura rectilínea delimitada por más de cuatro lados.



I.25

Un triángulo cuyos tres lados son iguales, se dice ser equilátero.



I.26

Un triángulo escaleno es uno que no tiene dos lados iguales.



I.27

Un triángulo escaleno es uno que no tiene dos lados iguales.

Un triángulo rectángulo es el que tiene un .



I.28

Un triángulo obtusángulo es aquel que tiene un .



I.29

Un triángulo acutángulo es aquel que tiene tres ángulos agudos.



I.30

De las figuras de cuatro lados, un cuadrado es aquel que tiene todos sus lados iguales y todos sus ángulos, ángulos rectos.



I.31

Un rombo es aquel que tiene todos sus lados iguales, pero sus ángulos no son ángulos rectos.



I.32

Un oblongo es aquel que tiene todos sus ángulos, ángulos rectos, pero no tiene todos sus lados iguales.



I.33

Un romboide es aquel que tiene sus lados opuestos iguales entre sí, pero todos sus lados no son iguales, ni sus ángulos son ángulos rectos.

I.34

Todas las demás figuras cuadriláteras se llaman trapecios.

I.35

Las líneas rectas paralelas son como las que se encuentran en el mismo plano, y que prolongadas continuamente en ambas direcciones, nunca se encontrarán.

Postulados

I.1

Deje que sea aceptado que una línea recta puede ser dibujada desde cualquier punto a cualquier otro punto.

I.2

Deje que sea aceptado que una línea recta finita puede ser prolongada a cualquier longitud en una línea recta.

I.3

Deje que sea aceptado que un círculo puede ser trazado con cualquier centro a cualquier distancia de ese centro.

Axiomas

I.1

Las magnitudes que son iguales a lo mismo son iguales entre sí.

I.2

Si se suma igual a igual, las sumas serán iguales.

I.3

Si se quita igual a igual, el residuo será igual.

I.4

Si se agregan iguales a desiguales, las sumas serán desiguales.

I.5

Si se eliminan iguales de desiguales, el residuo será desigual.

I.6

Los dobles de lo mismo o magnitudes iguales son iguales.

I.7

Las mitades de lo mismo o magnitudes iguales son iguales.

I.8

Las magnitudes que coinciden entre sí, o que llenan exactamente el mismo espacio, son iguales.

I.9

El todo es mayor que su parte.






I.10

Dos líneas rectas no pueden contener un espacio.

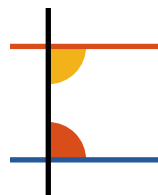
I.II

Todos los ángulos rectos son iguales.

I.I2


Si dos líneas rectas ( y ) se encuentran con una tercera línea recta () para hacer que los dos ángulos interiores ( y ) en el mismo lado sean menores que dos ángulos rectos, estas dos líneas rectas se encontrarán si se prolongan en el lado en el que los ángulos son menores que dos ángulos rectos. El duodécimo axioma puede ser expresado en cualquiera de las siguientes maneras:

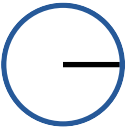
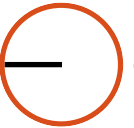


1. Dos líneas rectas divergentes no pueden ser ambas paralelas a la misma línea recta.
2. Si una línea recta corta una de dos líneas rectas paralelas, debe también cortar la otra.
3. Solo se puede trazar una línea recta a través de un punto dado, paralela a una línea recta dada.



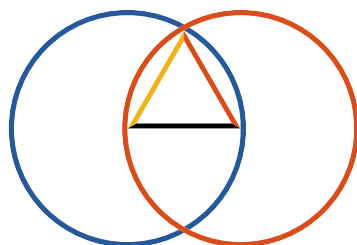
Proposiciones








I.I Prop. I. Prob.

E *n una línea recta finita dada () para trazar un triángulo equilátero.*

Traza  y  (post. I.3);
dibuja  y  (post. I.1).

Entonces  será equilátero.






Para  =  (def. I.15); y  = 
 (def. I.15), \therefore  =  (ax. I.1);
 y por lo tanto  es el triángulo equilátero
 requerido.

Q. E. D.  

Q. E. D.

D E un punto dado (— — — — —), dibujar una línea recta igual a una línea recta finita dada (— — — — —).

Dibuja — — — — — (post. I.1), traza  (prop. I.1),
prolonga — — — — — (post. I.2), traza  (post. I.3), y

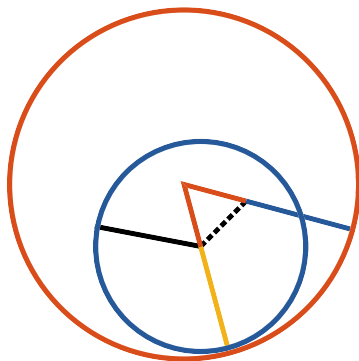
 (post. I.3); prolonga — — — — — (post. I.2),

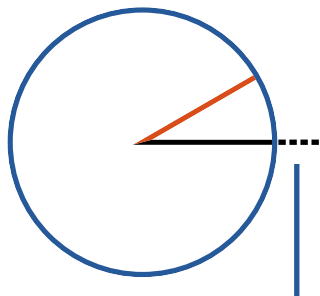
entonces — — — — — es la línea requerida.

Para — — — — — = — — — — — (def. I.15), y — — — — — = — — — — —
(conf.), \therefore — — — — — = — — — — — (const.), pero (post. I.3)
— — — — — = — — — — — = — — — — —; \therefore — — — — — dibujada de
un punto dado (— — — — —), es igual a la línea dada
— — — — —.

Q. E. D. (def. I.15)

Q. E. D.





FROM the greater (—) of two given straight lines, to cut off a part equal to the less (—).

Draw — = — (prop. I.2);

describe (—) (post. I.3),

then — = —

For — = — (def. I.15),

and — = — (const.);

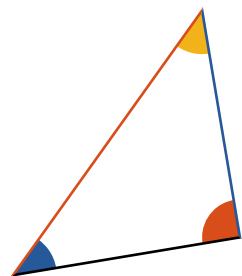
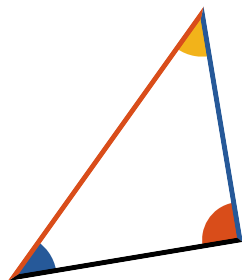
∴ — = — (ax. I.1).

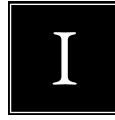
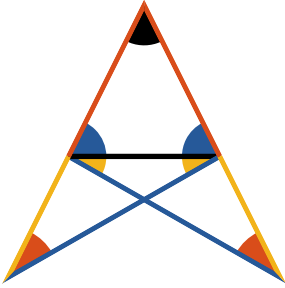
Q. E. D.


IF two triangles have two sides of the one respectively equal to two sides of the other, (— to — and — to —) and the angles (▲ and ▲) contained by those equal sides also equal; then their bases or their sides (— and —) are also equal: and the remaining angles opposite to equal sides are respectively equal (▲ = ▲ and ▲ = ▲): and the triangles are equal in every respect.







Let two triangles be conceived, to be so placed, that the vertex of the one of the equal angles, ▲ or ▲; shall fall upon that of the other, and — to coincide with —, then will — coincide with — if applied: consequently — will coincide with —, or two straight lines will enclose a space, which is impossible (ax. I.10), therefore — = —, ▲ = ▲ and ▲ = ▲, and as the triangles — and — coincide, when applied, they are equal in every respect.

Q. E. D.






In any isosceles triangle  if the equal sides be produced, the external angles at the base are equal, and the internal angles at the base are also equal.

Produce  and  (post. I.2),
take  =  (prop. I.3);
draw  and .

Then in  and 

we have  =  (const.),

 common to both,



and  =  (hyp.)

\therefore  = ,  =  and  = 

(prop. I.4).

Again in  and 

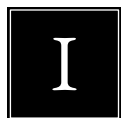
we have  = ,  =  and






 = ,

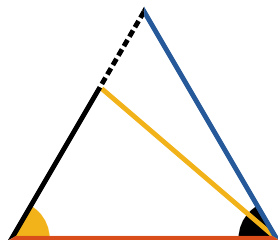
\therefore  =  and  =  (prop. I.4)






but  = , \therefore  =  (ax. I.3).








Q. E. D.



In any triangle () if two angles ( and ) are equal, the sides ( and ) opposite to them are also equal.





For if the sides be not equal, let one of them  be greater than the other , and from it to cut off  =  (prop. I.3), draw .

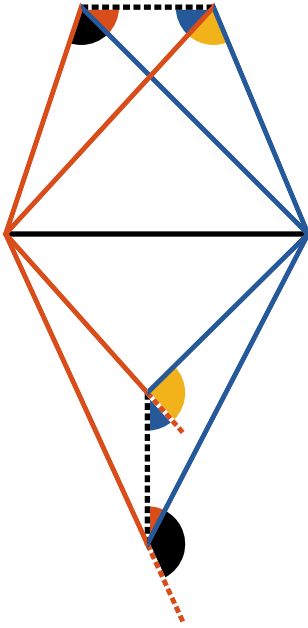
Then in  and ,
 =  (const.),
 =  (hyp.)
 and  common,

\therefore the triangles are equal (prop. I.4)

a part equal to the whole, which is absurd;

\therefore neither of the sides  or  is greater than the other,
 hence they are equal.

Q. E. D.



ON the same base (—), and on the same side of it there cannot be two triangles having their conterminous sides (— and —, — and —) at both extremities of the base, equal to each other.

When two triangles stand on the same base, and on the same side of it, the vertex of the one shall either fall outside of the other triangle, or within it; or, lastly, on one of its sides.









If it be possible let the two triangles be constructed so that $\left\{ \begin{array}{l} \text{—} = \text{—} \\ \text{—} = \text{—} \end{array} \right\}$, then draw and,







$$\left. \begin{array}{l} \triangle \text{ (black/orange)} = \triangle \text{ (blue/yellow)} \text{ (prop. I.5)} \\ \therefore \triangle \text{ (black/orange)} < \triangle \text{ (blue/yellow)} \text{ and} \\ \therefore \triangle \text{ (black/orange)} < \triangle \text{ (blue/yellow)} \end{array} \right\} \text{ which is absurd,}$$







but (prop. I.5) $\triangle \text{ (black/orange)} = \triangle \text{ (blue/yellow)}$

therefore the two triangles cannot have their conterminous sides equal at both extremities of the base.

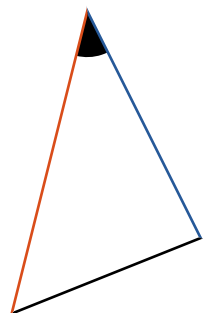
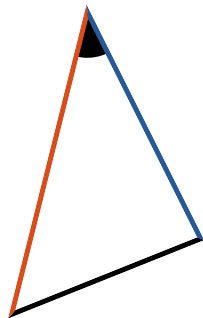
Q. E. D.

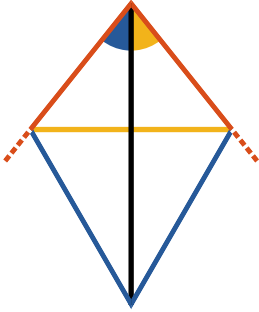
I F two triangles have two sides of the one respectively equal to two sides of the other ( =  and  = ) and also their bases ( = ), equal; then the angles ( and ) contained by their equal sides are also equal.


If the equal bases  and  be conceived to be placed one upon the other, so that the triangles shall lie at the same side of them, and that the equal sides  and  ,  and  be conterminous, the vertex of the one must fall on the vertex of the other; for to suppose them not coincident would contradict the last proposition.

Therefore sides  and  , being coincident with  and  , \therefore  =  .



Q. E. D.






o bisect a given rectilinear angle ().



Take  =  (prop. I.3)

draw , upon which describe  (prop. I.1),

draw .

\therefore  =  (const.)

and  common to the two triangles












and  =  (const.),

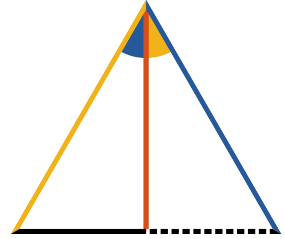
\therefore  =  (prop. I.8).

Q. E. D.

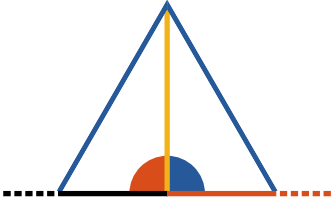


o bisect a given finite straight line (— ····).

Construct  (prop. I.1),
draw , making  =  (prop. I.9).
Then  =  by (prop. I.4),
for  =  (const.)  = 
and  common to the two triangles.
Therefore the given line is bisected.





Q. E. D.




FROM a given point (———), in a given straight line (———), to draw a perpendicular.

Take any point (———) in the given line,
cut off ——— = ——— (prop. I.3),

construct  (prop. I.1),
draw  and it shall be perpendicular to the given line.

For  =  (const.)

 =  (const.)

and  common to the two triangles.

Therefore  =  (prop. I.8)

∴  ⊥  (def. I.10).

Q. E. D.

To draw a straight line perpendicular to a given indefinite straight line (—) from a given point (↑) without.

With the given point ↑ as centre, at one side of the line, and any distance — capable of extending to the other side, describe ().

Make — = — (prop. I.10),

draw —, — and —,

then — ⊥ —.

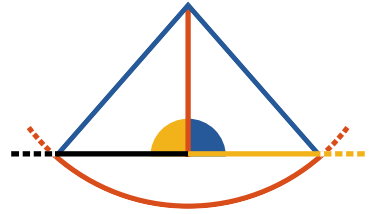
For (prop. I.8) since — = — (const.),

— common to both,

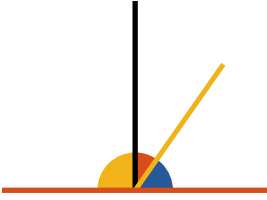
and — = — (def. I.15),

∴ () = (), and



















∴ — ⊥ — (def. I.10).








Q. E. D.

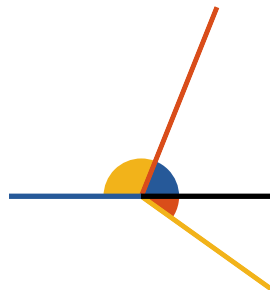


WHEN a straight line (—) standing upon another straight line (—) makes angles with it; they are either two right angles or together equal to two right angles.

If — be \perp to — then,
 and  =  (def. I.10),
 but if — be not \perp to — ,
 draw — \perp — (prop. I.11);
 +  =  (const.),
 =  =  + 
 \therefore  +  =  +  +  (ax. I.2)
 =  +  = .

Q. E. D.



I F two straight lines ( and ), meeting a third straight line (), at the same point, and at opposite sides of it, make with it adjacent angles ( and ) equal to two right angles; these straight lines lie in one continuous straight line.








For, if possible let , and not , be the continuation of ,

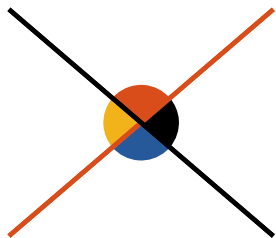
then  +  = 


but by the hypothesis  +  = 

\therefore  =  (ax. I.3); which is absurd (ax. I.9).

\therefore  is not the continuation of , and the like may be demonstrated of any other straight line except , \therefore  is the continuation of .

Q. E. D.



If two right lines (— and —) intersect one another, the vertical angles  *and*



are equal.







$$\therefore \text{yellow angle symbol} = \text{black angle symbol}.$$

In the same manner it may be shown that




$$\text{orange angle symbol} = \text{blue angle symbol}.$$

Q. E. D.

I

If a side of a triangle () is produced, the external angle () is greater than either of the internal remote angles ( or ).



Make  =  (prop. I.10);

Draw  and produce it until  =  ;

draw  .


In  and  ;

 =  ,  =  and




 =  (const. and prop. I.15),

\therefore  =  (prop. I.4),

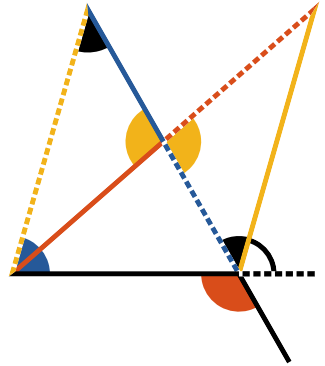
\therefore  >  .

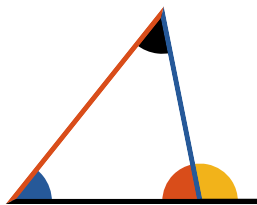
In like manner it can be shown, that if  be


produced,  >  .

and therefore  which is =  is >  .

Q. E. D.





ANY two angles of a triangle  are together less than two right angles.

Produce , then will






$$\text{red sector} + \text{yellow sector} = \text{semicircle}.$$

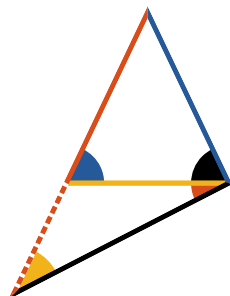
But  $>$  (prop. I.16)

$$\therefore \text{red sector} + \text{blue sector} < \text{semicircle},$$



and in the same manner it may be shown that any other two angles of the triangle taken together are less than two right angles.

Q. E. D.

I In any triangle  if one side  be greater than another , the angle opposite to the greater side is greater than the angle opposite to the less. I. e.  > .



Make  =  (prop. I.3), draw .

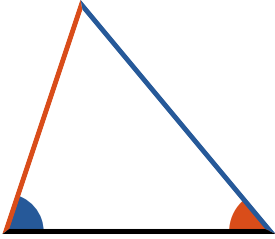
Then will  =  (prop. I.5);






but  >  (prop. I.16)



∴  >  and much more



is  > .


Q. E. D.



In any triangle  one angle  be greater than another  the side  which is opposite to the greater angle, is greater than the side  opposite the less.

If  be not greater than  then must

 = or < .

If  =  then

 =  (prop. I.5);

which is contrary to the hypothesis.

 is not less than ; for if it were,





 <  (prop. I.18)





which is contrary to the hypothesis:



\therefore  > .

Q. E. D.



ANY two sides  and  of a triangle  taken together are greater than the third side ().

Produce , and
make  =  (prop. I.3);
draw .

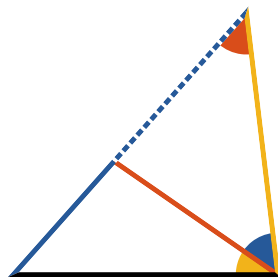
Then \therefore  =  (const.),

 =  (prop. I.5)

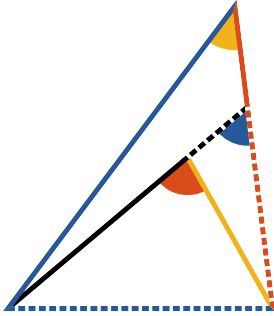
\therefore  >  (ax. I.9)

\therefore  +  >  (prop. I.19)



and \therefore  +  > .




Q. E. D.



I

From any point () within a triangle straight lines be drawn to the extremities of one side (), these lines must be together less than the other two sides, but must contain a greater angle.

Produce ,

 +  >  (prop. I.20),

add  to each,

 +  >  +  (ax. I.4)

in the same manner it may be shown that

 +  >  + ,

\therefore  +  >  + ,

which was to be proved.

Again  >  (prop. I.16),

and also  >  (prop. I.16),

\therefore  > .

Q. E. D.

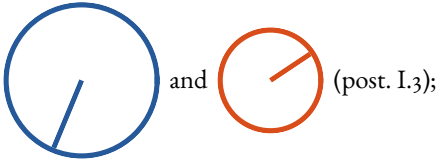


IVEN three right lines $\left\{ \begin{array}{l} \text{---} \\ \text{---} \\ \text{---} \end{array} \right\}$ the sum of any two greater than the third, to construct a triangle whose sides shall be respectively equal to the given lines.


Assume $\text{---} = \text{---}$ (prop. I.3).

Draw $\text{---} = \text{---}$
and $\text{---} = \text{---}$ } (prop. I.2).

With --- and --- as radii, describe

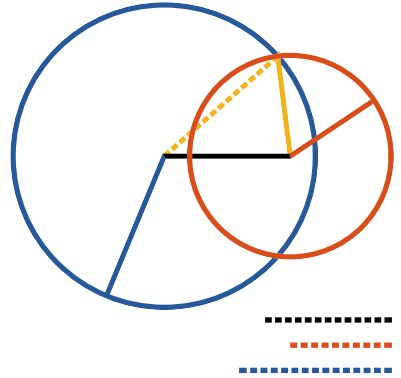


draw --- and --- ,




then will  be the triangle required.

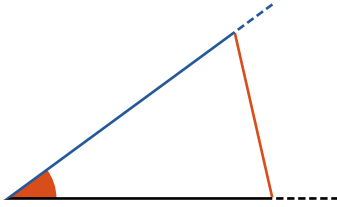
For $\text{---} = \text{---}$,
 $\text{---} = \text{---} = \text{---}$,
and $\text{---} = \text{---} = \text{---}$. } (const.)


Q. E. D.

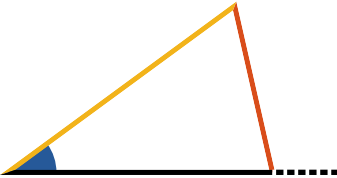













At a given point () in a given straight line (), to make an angle equal to a given rectilinear angle ().



Draw  between any two points in the legs of the given angle.

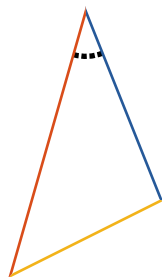
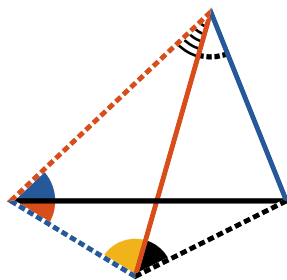


Construct  (prop. I.22)
so that  = ,  = 
and  = .
Then  =  (prop. I.8).

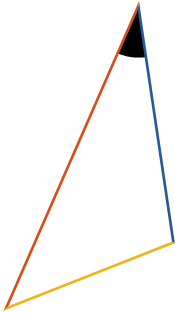
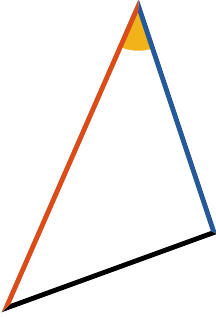
Q. E. D.

IF two triangles have two sides of the one respectively equal to two sides of the other (— to — and - - - - - to —), and if one of the angles (∠) contained by the equal sides be greater than the other (∠), the side (—) which is opposite to the greater angle is greater than the side (—) which is opposite to the less angle.

Make $\triangle ABC = \triangle DEF$ (prop. I.23),
 and $AB = DE$ (prop. I.3),
 draw BC and EF .
 $\therefore BC = EF$ (ax. I.1, hyp., and const.)
 $\therefore \angle B = \angle E$ (prop. I.5)
 but $\angle C < \angle F$,
 and $\therefore \angle A < \angle D$,
 $\therefore AB > DE$ (prop. I.19)
 but $DE = EF$ (prop. I.4)
 $\therefore AB > EF$.



Q. E. D.



IF two triangles have two sides (— and —) of the one respectively equal to two sides (— and —) of the other, but their bases unequal, the angle subtended by the greater base (—) of the one, must be greater than the angle subtended by the less base (—) of the other.

▲ = , > or < ▲

▲ is not equal to ▲

for if ▲ = ▲ then — = — (prop. I.4)
which is contrary to the hypothesis;

▲ is not less than ▲





for if ▲ < ▲
then — < — (prop. I.24),
which is also contrary to the hypothesis:

∴ ▲ > ▲.

Q. E. D.





If two triangles have two angles of the one respectively equal to two angles of the other

( =  and  = ) , and a side


of the one equal to a side of the other similarly placed with respect to the equal angles, the remaining sides and angles are respectively equal to one another.

Case I.

Let  and  which lie between the equal

angles be equal,



then  = .

For if it be possible, let one of them  be greater than the other;



make  =  , draw .



In  and  we have

 =  ,  =  ,  =  ;





\therefore  =  (pr. 4.)

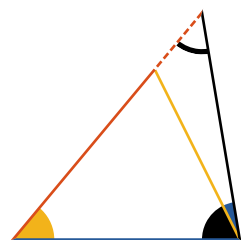
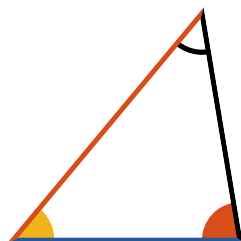
but  =  (hyp.)

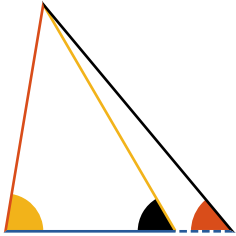
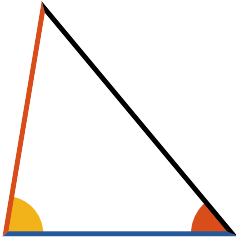
and therefore  =  , which is absurd;

hence neither of the sides  and  is greater than the other;

and \therefore they are equal;

\therefore  =  , and  =  , (prop. I.4).













Case II.



Again, let  = , which lie opposite the equal angles  and .



If it be possible, let  > , then take  = , draw .

Then in  and  we have
 = ,  =  and
 = ,

\therefore  =  (prop. I.4)

but  =  (hyp.)

\therefore  =  which is absurd (prop. I.16).

Consequently, neither of the sides  or  is greater than the other, hence they must be equal. It follows (by (prop. I.4)) that the triangles are equal in all respects.

Q. E. D.



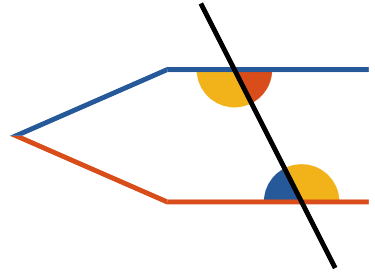
I F a straight line (—) meeting two other straight lines (— and —) makes with them the alternate angles (▲ and

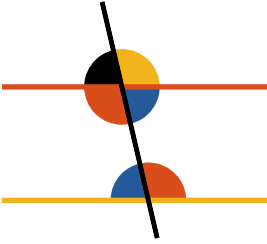
▼; ◐ and ◑) equal, these two straight lines are parallel.









If — be not parallel to — they shall meet when produced.





If it be possible, let those lines be not parallel, but meet when produced; then the external angle ▼ is greater than ▲ (prop. I.16), but they are also equal (hyp.), which is absurd: in the same manner it may be shown that they cannot meet on the other side; ∴ they are parallel.

Q. E. D.








IF a straight line (—), cutting two other straight lines (— and —), makes the external equal to the internal and opposite angle, at the same side of the cutting line (namely  =  or  = ), or if it makes the two internal angles at the same side ( and , or  and ) together equal to two right angles, those two straight lines are parallel.

First, if  = , then  =  (prop. I.15),

\therefore  =  \therefore — \parallel — (prop. I.27).

Secondly, if  +  = ,

then  +  =  (prop. I.13),

\therefore  +  =  +  (ax. I.3)

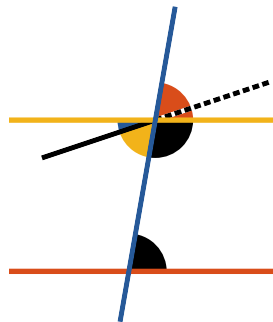
\therefore  = 

\therefore — \parallel — (prop. I.27).

Q. E. D.














STRAIGHT line (—) falling on two parallel straight lines (— and —), makes the alternate angles equal to one another; and also the external equal to the internal and opposite angle on the same side; and the two internal angles on the same side together equal to two right angles.



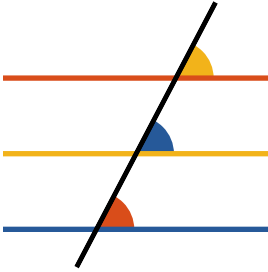
For if the alternate angles  and  be not equal, draw —, making  =  (prop. I.23).

Therefore — — — — — || — (prop. I.27) and therefore two straight lines which intersect are parallel to the same straight line, which is impossible (ax. I.12).

Hence  and  are not unequal, that is, they are equal:  =  (prop. I.15); \therefore  = , the external angle equal to the internal and opposite on the same side: if  be added to both, then  +  =

 =  (prop. I.13). That is to say, the two internal angles at the same side of the cutting line are equal to two right angles.

Q. E. D.



S TRAIGHT lines (— and —)
 which are parallel to the same straight line
 (—), are parallel to one another.

Let — intersect { — };

Then,  =  =  (prop. I.29),









\therefore  = 

\therefore — \parallel — (prop. I.28).

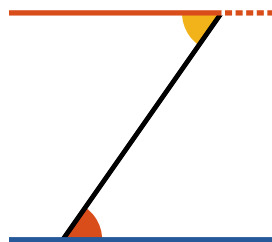
Q. E. D.

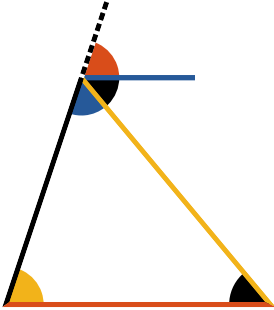





FROM a given point  to draw a straight line parallel to a given straight line ().

Draw  from the point  to any point  in
,
 make  =  (prop. I.23),
 then  ||  (prop. I.27).

Q. E. D.





If any side (—) of a triangle be produced,
the external angle () is equal to the sum of
the two internal and opposite angles ( and
), and the three internal angles of any triangle taken
together are equal to two right angles.

Through the point  draw
 \parallel  (prop. I.31).

Then $\left\{ \begin{array}{l} \text{red sector} = \text{yellow sector} \\ \text{black sector} = \text{black sector} \end{array} \right\}$ (prop. I.29),

$\therefore \text{yellow sector} + \text{black sector} = \text{red sector}$ (ax. I.2),

and therefore

 +  +  =  =  (prop. I.13).

Q. E. D.



STRAIGHT lines (— and —) which join the adjacent extremities of two equal and parallel straight lines (— and —), are themselves equal and parallel.

Draw — the diagonal.

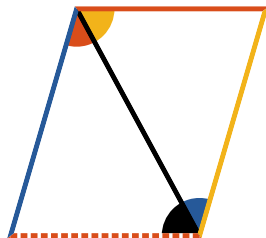
— = — (hyp.)

∠ = ∠ (prop. I.29)

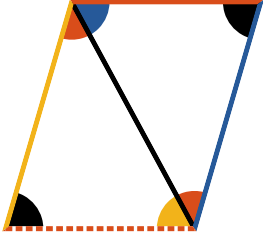
and — common to the two triangles;

∴ — = —, and ∠ = ∠ (prop. I.4);

and ∴ — || — (prop. I.27).





Q. E. D.



THE opposite sides and angles of any parallelogram are equal, and the diagonal (—) divides it into two equal parts.







$$\begin{aligned} &\text{Since } \left\{ \begin{array}{l} \text{blue sector} = \text{yellow sector} \\ \text{red sector} = \text{red sector} \end{array} \right\} \text{ (prop. I.29)} \\ &\text{and } \text{—} \text{ common to the two triangles.} \\ &\therefore \left\{ \begin{array}{l} \text{red side} = \text{red side} \\ \text{yellow side} = \text{blue side} \\ \text{black sector} = \text{black sector} \end{array} \right\} \text{ (prop. I.26)} \\ &\text{and } \text{blue sector} = \text{yellow sector} \text{ (ax. I.2).} \end{aligned}$$

Therefore the opposite sides and angles of the parallelogram are equal: and as the triangles  and  are equal in every respect (prop. I.4), the diagonal divides the parallelogram into two equal parts.

Q. E. D.

P

PARALLELOGRAMS *on the same base, and between the same parallels, are (in area) equal.*

On account of the parallels,
 =  ; { (prop. I.29)
 =  ; { (prop. I.29)
and  =  } (prop. I.34).

But  =  (prop. I.8)

∴  -  =  ,



and  -  =  ;

∴  =  .





Q. E. D.



PARALLELOGRAMS ( and ) on equal bases, and between the same parallels, are equal.

Draw  and 

 =  =  by (prop. I.34 and hyp.);

\therefore  = and \parallel ;

\therefore  = and \parallel  (prop. I.33)



And therefore  is a parallelogram:

but  =  =  (prop. I.35)



\therefore  =  (ax. I.1).

Q. E. D.

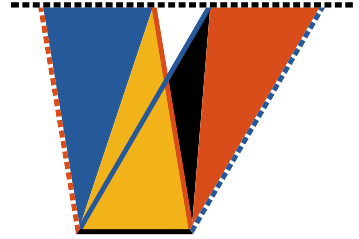


TRIANGLES  and  on the same base
 (—) and between the same parallels are
 equal.

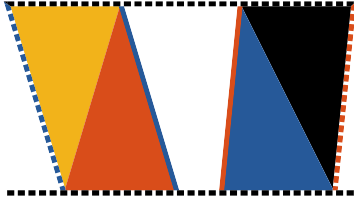
Draw  ||  } (prop. I.31)
 || 
 Produce .



 and  are parallelograms on the same base
 and between the same parallels, and therefore equal.
 (prop. I.35)

$\therefore \left\{ \begin{array}{l} \text{blue and yellow parallelogram} = \text{twice yellow triangle} \\ \text{yellow and black parallelogram} = \text{twice yellow triangle} \end{array} \right\} \text{ (prop. I.34)}$
 $\therefore \text{yellow triangle} = \text{yellow triangle with black top-right corner}.$



Q. E. D.



TRIANGLES ( and ) on equal bases and between the same parallels are equal.

Draw  ||  } (prop. I.31)
and  || 

$$\begin{array}{c} \text{yellow triangle} \\ \text{red triangle} \end{array} = \begin{array}{c} \text{blue triangle} \\ \text{black triangle} \end{array} \quad (\text{prop. I.36});$$

$$\text{but } \begin{array}{c} \text{yellow triangle} \\ \text{red triangle} \end{array} = \text{twice } \begin{array}{c} \text{red triangle} \end{array} \quad (\text{prop. I.34}),$$



$$\text{and } \begin{array}{c} \text{blue triangle} \\ \text{black triangle} \end{array} = \text{twice } \begin{array}{c} \text{blue triangle} \end{array} \quad (\text{prop. I.34}),$$

$$\therefore \begin{array}{c} \text{red triangle} \end{array} = \begin{array}{c} \text{blue triangle} \end{array} \quad (\text{ax. I.7}).$$

Q. E. D.

E

QUAL triangles  and  on the same base (—) and on the same side of it, are between the same parallels.

If , which joins the vertices of the triangles, be not \parallel —, draw  \parallel — (prop. I.31),



meeting




Draw .

\therefore  \parallel — (const.)

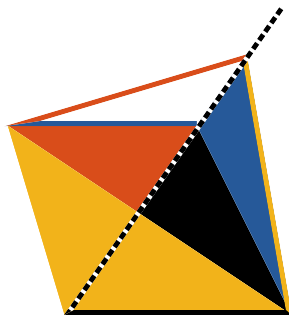
 =  (prop. I.37);

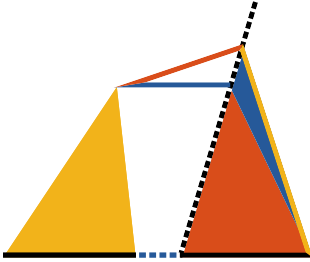
but  =  (hyp.);



\therefore  = , a part equal to the whole, which is absurd.


\therefore  \nparallel —; and in the same manner it can be demonstrated, that no other line except  is \parallel —; \therefore  \parallel —.





Q. E. D.





QUAL triangles ( and ) on equal bases, and on the same side, are between the same parallels.



If  which joins the vertices of triangles be not



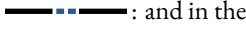

draw   ,
meeting .

Draw .

\therefore    (const.)

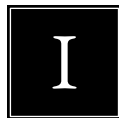
 =  but  = 

\therefore  = , a part equal to the whole, which is absurd.

\therefore   : and in the same manner it can be demonstrated, that no other line except  is

 : \therefore   .

Q. E. D.



If a parallelogram



and a triangle



are upon the same base — and
between the same parallels and



—, the parallelogram is double the triangle.



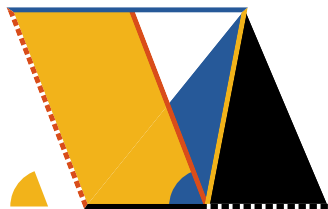
Draw — the diagonal.

Then  =  (prop. I.37)

 = twice  (prop. I.34)

\therefore  = twice .

Q. E. D.



To construct a parallelogram equal to a given triangle  and having an angle equal to a given rectilinear angle .

Make  =  (prop. I.10)

Draw .

Make  =  (prop. I.23)

Draw $\left\{ \begin{array}{l} \text{---} \parallel \text{---} \\ \text{---} \parallel \text{---} \end{array} \right\}$ (prop. I.31)



 = twice  (prop. I.41)

but  =  (prop. I.38)

\therefore  =  .

Q. E. D.

T

HE complements  and  of the parallelograms which are about the diagonal of a parallelogram are equal.



(prop. I.34)

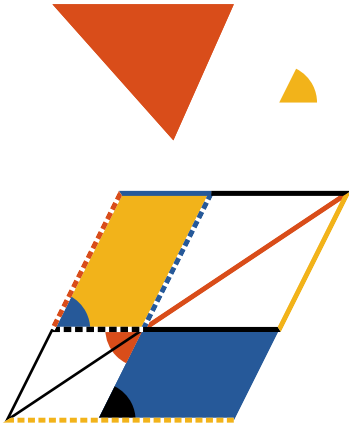


(prop. I.34)



(ax. I.3).

Q. E. D.



To a given straight line (—) to apply a parallelogram equal to a given triangle (▲), and having an angle equal to a given rectilinear angle (▲).

Make ▲ = ▲ with ▲ = ▲ (prop. I.42)
 and having one of its sides conterminous with
 and in continuation of —.


Produce — till it meets ▲ ||
 draw — produce it till it meets continued;
 draw || — meeting — produced and
 produce



▲ = ▲ (prop. I.43)
 but ▲ = ▲ (const.)
 \therefore ▲ = ▲ ;
 and ▲ = ▲ = ▲ = ▲ (prop. I.29 and const.).

Q. E. D.



o construct a parallelogram equal to a given
rectilinear figure () and having an

angle equal to a given rectilinear angle ().



Draw  and  dividing the rectilinear
figure into triangles.

Construct  = 

having  =  (prop. I.42)


to  apply  = 

having  =  (prop. I.44)

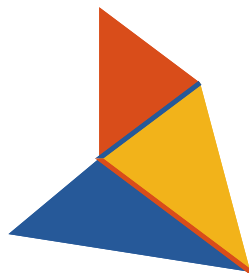
to  apply  = 

having  =  (prop. I.44)

\therefore  = 

and  is a parallelogram. (prop. I.14, I.29
and I.30)

having  = .



Q. E. D.






UPON a given straight line (—) to construct a square.

Draw — \perp and = — (prop. I.3 and I.11)

Draw — \parallel — ,
and meeting — drawn \parallel — .

In  — = — (const.)

 = a right angle (const.)

\therefore  =  = a right angle (prop. I.29),
and the remaining sides and angles must be equal
(prop. I.34).

And \therefore  is a square (def. I.30).

Q. E. D.

I

In a right angled triangle the square on the hypotenuse is equal to the sum of the squares of the sides (and).



On , , describe squares,
(prop. I.46)

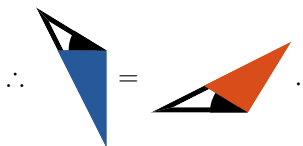
Draw || (prop. I.31)

also draw and .

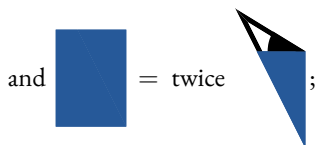
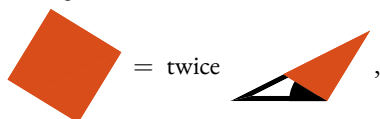


To each add . \therefore = ,

= and =;

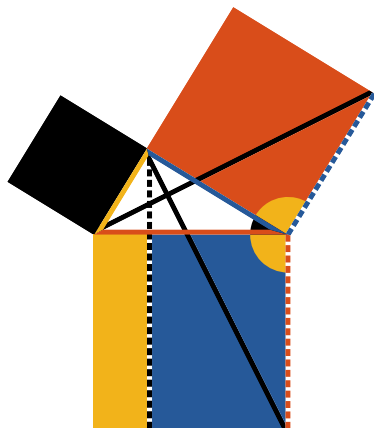


Again, \therefore ||

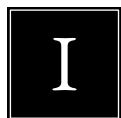


In the same manner it may be shown that = ;

hence = .



Q. E. D.



If the square of one side (—) of a triangle is equal to the squares of the other two sides (— and —), the angle (◐) subtended by that side is a right angle.

Draw \perp — and = — (prop. I.3 and I.11)

and draw also.

Since = — (const.)

$$\text{.....}^2 = \text{---}^2;$$

$$\therefore \text{.....}^2 + \text{---}^2 = \text{---}^2 + \text{---}^2$$

$$\text{but } \text{.....}^2 + \text{---}^2 = \text{.....}^2 \text{ (prop. I.47),}$$

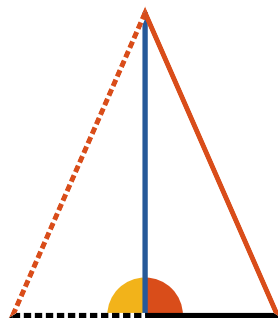
$$\text{and } \text{---}^2 + \text{---}^2 = \text{---}^2 \text{ (hyp.)}$$

$$\therefore \text{.....}^2 = \text{---}^2,$$

$$\therefore \text{.....} = \text{---};$$

$$\text{and } \therefore \text{◑} = \text{◐} \text{ (prop. I.8),}$$

consequently ◐ is a right angle.



Q. E. D.








Book II







II.1 Definition I



RECTANGLE or a *right angled parallelogram* is said to be contained by any two of its adjacent or conterminous sides.



Thus: the right angled parallelogram  is said to be contained by the sides  and ; or it may be briefly designated by  · .

If the adjacent sides are equal; i. e.  = , then  ·  which is the expression for the rectangle under  and  is a square, and

$$\text{is equal to } \left\{ \begin{array}{l} \text{---} \cdot \text{---} \text{ or } \text{---}^2 \\ \text{---} \cdot \text{---} \text{ or } \text{---}^2 \end{array} \right.$$

II.2 Definition II



IN a parallelogram, the figure composed of one of the parallelograms about the diagonal, together with the two complements, is called a *Gnomon*.

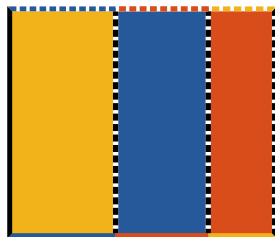
Thus  and  are called Gnomons.



THE rectangle contained by two straight lines,
one of which is divided into any number of

$$\text{parts, } \text{---} \cdot \text{---} = \begin{cases} \text{---} \cdot \text{---} \\ + \text{---} \cdot \text{---} \\ + \text{---} \cdot \text{---} \end{cases}$$

is equal to the sum of the rectangles contained by the
undivided line, and the several parts of the divided line.



Draw $\text{---} \perp \text{---}$ and $= \text{---}$ (prop. I.3 and I.11);
complete the parallelograms, that is to say,

$$\text{draw } \left\{ \begin{array}{l} \text{---} \parallel \text{---} \\ \text{---} \parallel \text{---} \end{array} \right\} \text{ (prop. I.31)}$$

$$\text{---} = \text{---} + \text{---} + \text{---}$$

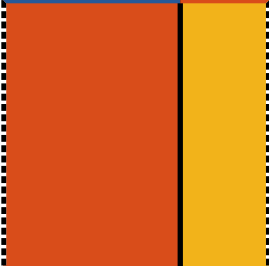
$$\text{---} = \text{---} \cdot \text{---}$$

$$\text{---} = \text{---} \cdot \text{---}, \text{---} = \text{---} \cdot \text{---},$$

$$\text{---} = \text{---} \cdot \text{---}$$

$$\therefore \text{---} = \text{---} + \text{---} + \text{---}.$$

Q. E. D.





If a straight line be divided into any two parts
, the square of the whole line is equal
to the sum of the rectangles contained by the
whole line and each of its parts.

$$\text{---}^2 = \left\{ \begin{array}{l} \text{---} \cdot \text{---} \\ + \text{---} \cdot \text{---} \end{array} \right.$$



Describe (prop. I.46)

Draw  parallel to  (prop. I.31)



$$= \text{---}^2$$



$$= \text{---} \cdot \text{---} = \text{---} \cdot \text{---}$$




$$= \text{---} \cdot \text{---} = \text{---} \cdot \text{---}$$



$$= +$$

$$\therefore \text{---}^2 = \text{---} \cdot \text{---} + \text{---} \cdot \text{---}$$

Q. E. D.

IF a straight line be divided into any two parts
, the rectangle contained by the
 whole line and either of its parts, is equal
 to the square of that part, together with the
 rectangle under the parts.

$$\begin{aligned} \text{---} \cdot \text{---} &= \text{---}^2 + \text{---} \cdot \text{---}, \text{ or} \\ \text{---} \cdot \text{---} &= \text{---}^2 + \text{---} \cdot \text{---}. \end{aligned}$$








Describe  (prop. I.46)

Describe  (prop. I.31)

Then  =  + , but

 =  ·  and

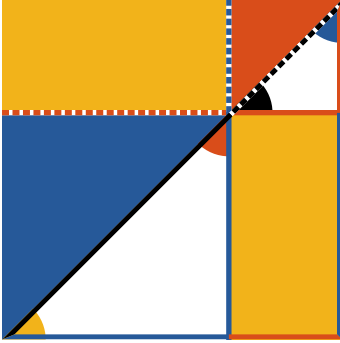
 = ²,  =  · ,

$$\therefore \text{---} \cdot \text{---} = \text{---}^2 + \text{---} \cdot \text{---}.$$

In a similar manner it may be readily shown that



$$\text{---} \cdot \text{---} = \text{---}^2 + \text{---} \cdot \text{---}.$$

Q. E. D.



IF a straight line be divided into any two parts
 —, the square of the whole line is equal
 to the squares of the parts, together with twice
 the rectangle contained by the parts.

$$\text{—}^2 = \text{—}^2 + \text{—}^2 + \text{twice } \text{—} \cdot \text{—}$$

Describe  (prop. I.46)
 draw  (post. I.1)
 and $\left\{ \begin{array}{l} \text{—} \parallel \text{—} \\ \text{—} \parallel \text{—} \end{array} \right\}$ (prop. I.31)

$$\triangle = \triangle \text{ (prop. I.5),}$$

$$\triangle = \triangle \text{ (prop. I.29),}$$





$$\therefore \triangle = \triangle$$

\therefore by (prop. I.6, I.29 and I.34)

$$\triangle \text{ is a square } = \text{—}^2.$$

For the same reasons  is a square $= \text{—}^2$,






$$\text{—} = \text{—} = \text{—} \cdot \text{—} \text{ (prop. I.43)}$$

But  =  +  + ,

$$\therefore \text{—}^2 = \text{—}^2 + \text{—}^2 + \text{twice } \text{—} \cdot \text{—}.$$

Q. E. D.



*F*a straight line be divided   into two equal parts and also    into two unequal parts, the rectangle contained by the unequal parts, together with the square of the line between the points of section, is equal to the square of half that line

$$\text{red} \cdot \text{blue} + \text{blue}^2 = \text{yellow}^2 = \text{red} \cdot \text{blue}.$$

Describe  (prop. I.46),

draw 

and $\left\{ \begin{array}{l} \text{red} \cdots \parallel \text{red} \cdots \\ \cdots \parallel \text{red} \cdots \\ \text{red} \cdots \parallel \text{red} \cdots \end{array} \right\} \text{ (prop. I.31)}$

$$\text{black} = \text{blue} \quad (\text{prop. I.36})$$

$$\text{yellow} = \text{yellow} \quad (\text{prop. I.43})$$

$$\therefore (\text{ax. I.2}) \quad \text{blue} \cdot \text{yellow} = \text{black} = \text{red} \cdot \text{blue} \quad \text{but}$$

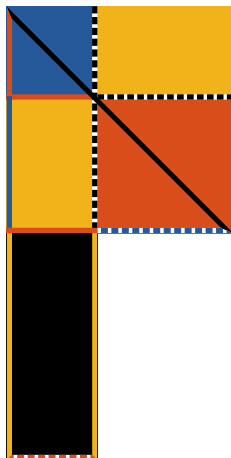
$$\text{red} = \text{blue}^2 \quad (\text{prop. II.4})$$

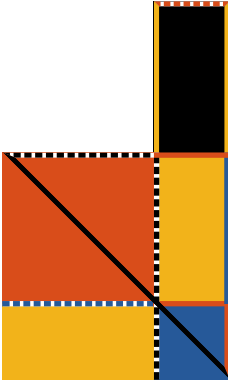
$$\text{and} \quad \text{blue} \cdot \text{yellow} = \text{red} \cdot \text{blue}^2 \quad (\text{const.})$$





$$\therefore (\text{ax. I.2}) \quad \text{blue} \cdot \text{yellow} = \text{black}$$

$$\therefore \text{red} \cdot \text{blue} + \text{blue}^2 = \text{yellow}^2 = \text{red} \cdot \text{blue}^2.$$



Q. E. D.





IF a straight line be bisected  and produced to any point   , the rectangle contained by the whole line so increased, and the part produced, together with the square of half the line, is equal to the square of the line made up of the half, and the produced part.

$$\text{red} \cdot \text{red} + \text{blue}^2 = \text{red}^2$$

Describe  (prop. I.46), draw 
and $\left\{ \begin{array}{l} \text{blue} \cdot \text{red} \parallel \text{red} \cdot \text{black} \\ \text{black} \cdot \text{yellow} \parallel \text{red} \cdot \text{blue} \cdot \text{yellow} \\ \text{red} \cdot \text{red} \parallel \text{red} \cdot \text{black} \end{array} \right\}$ (prop. I.31)

$$\text{yellow} = \text{yellow} = \text{black} \quad (\text{prop. I.36 and I.43})$$

$$\therefore \text{yellow} = \text{blue} = \text{red} \cdot \text{red} \cdot \text{yellow};$$


$$\text{but } \text{red} = \text{blue}^2 \quad (\text{prop. II.4})$$

$$\therefore \text{red} = \text{blue}^2 = \text{red} \cdot \text{red} \cdot \text{yellow} \quad (\text{const. and ax. I.2})$$

$$\therefore \text{red} \cdot \text{red} + \text{blue}^2 = \text{red}^2.$$


Q. E. D.



F a straight line be divided into any two parts
, *the squares of the whole line and one*
of the parts are equal to twice the rectangle con-
tained by the whole line and that part, together
with the square of the other parts.

$$\text{---}^2 + \text{---}^2 = 2 \text{---} \cdot \text{---} + \text{---}^2$$





Describe (prop. I.46), draw 
 (post. I.1),

and $\left\{ \begin{array}{l} \text{---} \text{---} \parallel \text{---} \\ \text{---} \text{---} \parallel \text{---} \end{array} \right\}$



(prop. I.43),

add  = ² to both (prop. II.4)

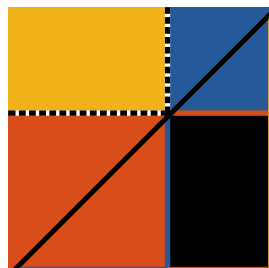
$$\begin{array}{c} \text{---} \text{---} \\ \text{---} \text{---} \end{array} = \begin{array}{c} \text{---} \\ \text{---} \end{array} = \text{---} \cdot \text{---}$$

$$\text{---} = \text{---}^2 \text{ (prop. II.4)}$$

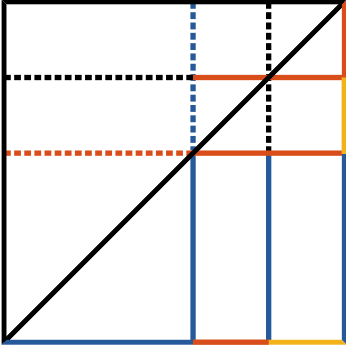
$$\begin{array}{c} \text{---} \text{---} \\ \text{---} \end{array} + \begin{array}{c} \text{---} \\ \text{---} \end{array} + \text{---} =$$

$$2 \text{---} \cdot \text{---} + \text{---}^2 = \begin{array}{c} \text{---} \text{---} \\ \text{---} \text{---} \end{array} + \text{---};$$

$$\text{---}^2 + \text{---}^2 = 2 \text{---} \cdot \text{---} + \text{---}^2.$$



Q. E. D.



IF a straight line be divided into any two parts
 ————, the square of the sum of the whole
 line and any one of its parts is equal to four
 times the rectangle contained by the whole line,
 and that part together with the square of the other part.

$$\text{—————}^2 = 4 \cdot \text{—————} \cdot \text{———} + \text{—————}^2$$

Produce ———— and make ———— = ————



Construct ———— (prop. I.46);

draw ————,

$\left. \begin{array}{l} \text{—————} \\ \text{—————} \end{array} \right\} \parallel \left. \begin{array}{l} \text{—————} \\ \text{—————} \end{array} \right\} \text{ (prop. I.31)}$

$$\text{—————}^2 = \text{—————}^2 + \text{—————}^2 + 2 \cdot \text{—————} \cdot \text{———}$$






(prop. II.4)

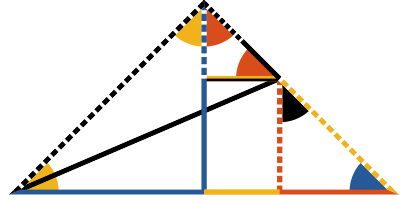
$$\text{but } \text{———}^2 + \text{—————}^2 = 2 \cdot \text{—————} \cdot \text{———} + \text{—————}^2$$

(prop. II.7)




$$\therefore \text{—————}^2 = 4 \cdot \text{—————} \cdot \text{———} + \text{—————}^2.$$



Q. E. D.

I F a straight line be divided into two equal parts   and also into two unequal parts   , the squares of the unequal parts are together double the squares of half the line, and of the part between the points of section.







$$\text{blue}^2 + \text{red}^2 = 2 \cdot \text{blue}^2 + 2 \cdot \text{yellow}^2$$


Make  \perp and $=$  or ,

Draw  and ,

 \parallel ,  \parallel  and draw .

 $=$  (prop. I.5) $=$ half a right angle (prop. I.32)

 $=$  (prop. I.5) $=$ half a right angle (prop. I.32)

\therefore  $=$ a right angle.

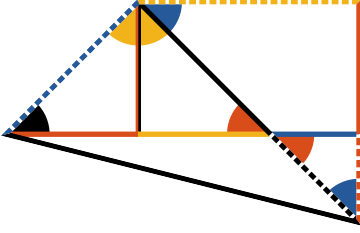
 $=$  $=$  $=$  (prop. I.5 and I.29).



hence  $=$ ,  $=$  $=$  (prop. I.6 and I.34)

$$\left\{ \begin{array}{l} \text{blue}^2 + \text{red}^2, \text{ or } + \text{red}^2 \\ = \left\{ \begin{array}{l} = \text{dotted}^2 + \text{dashed}^2 \\ = 2 \cdot \text{blue}^2 + 2 \cdot \text{yellow}^2 \end{array} \right. \end{array} \right. \text{ (prop. I.47)}$$




$$\therefore \text{blue}^2 + \text{red}^2 = 2 \cdot \text{blue}^2 + 2 \cdot \text{yellow}^2.$$



Q. E. D.



IF a straight line  be bisected and produced to any point , the squares of the whole produced line, and of the produced part, are together double of the squares of the halfline, and of the line made up of the half and produced part.



$$\text{red}^2 + \text{blue}^2 = 2 \cdot \text{yellow}^2 + 2 \cdot \text{yellow} \cdot \text{blue}^2$$


Make  \perp and $=$ to  or ,


draw  and ,

and $\left\{ \begin{array}{l} \text{red} \dots \parallel \text{red} \\ \text{yellow} \dots \parallel \text{yellow} \end{array} \right\}$ (prop. I.31)

draw  also.

 =  (prop. I.5) = half a right angle (prop. I.32)

 =  (prop. I.5) = half a right angle (prop. I.32)

\therefore  = a right angle.

 =  =  =  =  =

half a right angle (prop. I.5, I.29, I.32 and I.34),

and  = ,  =  = ,


(prop. I.6 and I.34).

Hence by (prop. I.47)

$$\begin{aligned} \text{black}^2 &= \left\{ \begin{array}{l} \text{red} \cdot \text{yellow} \cdot \text{blue}^2 + \text{red}^2 \text{ or } \text{blue}^2 \\ \left\{ \begin{array}{l} + \text{dotted blue}^2 = 2 \cdot \text{red}^2 \\ + \text{black} \cdot \text{dotted black}^2 = 2 \cdot \text{dotted yellow}^2 \end{array} \right. \end{array} \right. \\ \therefore \text{red}^2 + \text{blue}^2 &= 2 \cdot \text{yellow}^2 + 2 \cdot \text{yellow} \cdot \text{blue}^2. \end{aligned}$$

Q. E. D.

T

o divide a given straight line  in such a manner, that the rectangle contained by the whole line and one of its parts may be equal to the square of the other.

$$\text{---} \cdot \text{---} = \text{---}^2$$



Describe  (prop. I.46),

make  =  (prop. I.10),

draw ,

take   =  (prop. I.3),

on  describe  (prop. I.46).

Produce  (post. I.2).

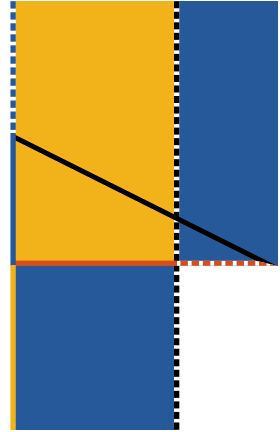
Then, (prop. II.6)    +  ² =

$$\text{---} \cdot \text{---}^2 = \text{---}^2 = \text{---} \cdot \text{---}^2 + \text{---}^2 \therefore$$

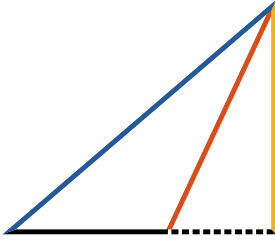
$$\text{---} \cdot \text{---} \cdot \text{---} = \text{---}^2, \text{ or,}$$



$$\therefore \text{---} \cdot \text{---} \cdot \text{---} = \text{---}^2.$$



Q. E. D.



IN any obtuse angled triangle, the square of the side subtending the obtuse angle exceeds the sum of the squares of the sides containing the obtuse angle, by twice the rectangle contained by either of these sides and the produced parts of the same from the obtuse angle to the perpendicular let fall on it from the opposite acute angle.

$$\text{blue}^2 > \text{black}^2 + \text{red}^2 \text{ by } 2 \cdot \text{black} \cdot \text{dashed}$$

By (prop. II.4)

$$\text{dashed}^2 = \text{black}^2 + \text{yellow}^2 + 2 \cdot \text{black} \cdot \text{dashed};$$

add yellow^2 to both

$$\text{black}^2 + \text{yellow}^2 = \text{blue}^2 \text{ (prop. I.47)}$$

$$= 2 \cdot \text{black} \cdot \text{dashed} + \text{black}^2 + \left\{ \begin{array}{l} \text{dashed}^2 \\ \text{yellow}^2 \end{array} \right\} \text{ or}$$

+ red^2 (prop. I.47).

$$\therefore \text{blue}^2 = 2 \cdot \text{black} \cdot \text{dashed} + \text{black}^2 + \text{red}^2;$$

$$\text{hence } \text{blue}^2 > \text{black}^2 + \text{red}^2 \text{ by}$$

$$2 \cdot \text{black} \cdot \text{dashed}.$$

Q. E. D.



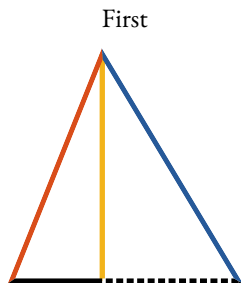
N any triangle, the square of the side subtending an acute angle, is less than the sum of the squares of the sides containing that angle, by twice the rectangle contained by either of these sides, and the part of it intercepted between the foot of the perpendicular let fall on it from the opposite angle, and the angular point of the acute angle.

First.

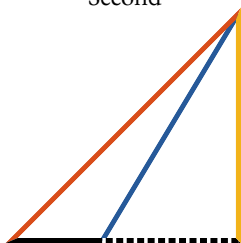
$$\text{blue}^2 < \text{dashed}^2 + \text{orange}^2 \text{ by } 2 \cdot \text{dashed} \cdot \text{black}.$$

Second.

$$\text{blue}^2 < \text{orange}^2 + \text{black}^2 \text{ by } 2 \cdot \text{black} \cdot \text{dashed}.$$



Second



First, suppose the perpendicular to fall within the triangle, then (prop. II.7)

$$\text{dashed}^2 + \text{black}^2 = 2 \cdot \text{dashed} \cdot \text{black} + \text{dashed}^2,$$

add to each yellow^2 then,

$$\text{dashed}^2 + \text{black}^2 + \text{yellow}^2 = 2 \cdot \text{dashed} \cdot \text{black} + \text{dashed}^2 + \text{yellow}^2$$

\therefore (prop. I.47)

$$\text{dashed}^2 + \text{orange}^2 = 2 \cdot \text{dashed} \cdot \text{black} + \text{blue}^2,$$

$$\text{and } \therefore \text{blue}^2 < \text{dashed}^2 + \text{orange}^2 \text{ by } 2 \cdot \text{dashed} \cdot \text{black}$$

Next suppose the perpendicular to fall without the triangle, then (prop. II.7)

$$\text{dashed}^2 + \text{black}^2 = 2 \cdot \text{dashed} \cdot \text{black} + \text{dashed}^2,$$

add to each yellow^2 then

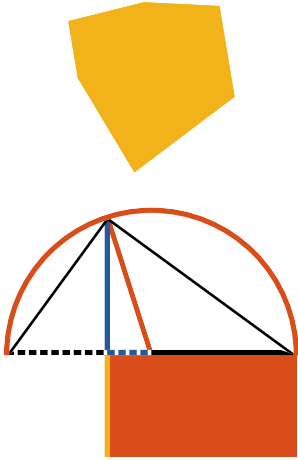
$$\text{dashed}^2 + \text{black}^2 + \text{yellow}^2 = 2 \cdot \text{dashed} \cdot \text{black} + \text{dashed}^2 + \text{yellow}^2$$

\therefore (prop. I.47)


$$\text{orange}^2 + \text{black}^2 = 2 \cdot \text{dashed} \cdot \text{black} + \text{blue}^2,$$




$$\therefore \text{blue}^2 < \text{orange}^2 + \text{black}^2 \text{ by } 2 \cdot \text{dashed} \cdot \text{black}.$$








Q. E. D.



To draw a right line of which the square shall be equal to a given rectilinear figure.

To draw --- such that, $\text{---}^2 =$ 

Make  =  (prop. I.45), produce --- until $\text{---} =$  ;
take $\text{---} =$ --- (prop. I.10).

Describe  (post. I.3),
and produce  to meet it: draw  .
 ---^2 or  $^2 =$ $\text{---} \cdot \text{---} + \text{---}^2$ (prop. II.5),
but  $^2 =$ $\text{---}^2 + \text{---}^2$ (prop. I.47);
 $\therefore \text{---}^2 + \text{---}^2 = \text{---} \cdot \text{---} + \text{---}^2$
 $\therefore \text{---}^2 = \text{---} \cdot \text{---}$, and
 $\therefore \text{---}^2 =$  = .

Q. E. D.

Book III

Definitions

III.1

Equal circles are those whose diameters are equal.

III.2

A right line is said to touch a circle when it meets the circle, and being produced does not cut it.



III.3

Circles are said to touch one another which meet, but do not cut one another.



III.4

Right lines are said to be equally distant from the centre of a circle when the perpendiculars drawn to them from the centre are equal.



III.5

And the straight line on which the greater perpendicular falls is said to be farther from the centre.

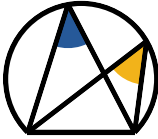
III.6

A segment of a circle is the figure contained by a straight line and the part of the circumference it cuts off.



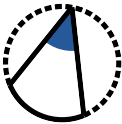
III.7

An angle of a segment is that contained by a straight line and a circumference of a circle.



III.8

An angle in a segment is the angle contained by two straight lines drawn from any point in the circumference of the segment to the extremities of the straight line which is the base of the segment.



III.9

An angle is said to stand on the part of the circumference, or the arch, intercepted between the right lines that contain the angle.



III.10

A sector of a circle is the figure contained by two radii and the arch between them.



III.11

Similar segments of circles are those which contain equal angles.









III.12




Circles which have the same centre are called *concentric circles*.












T






o find the centre of a given circle



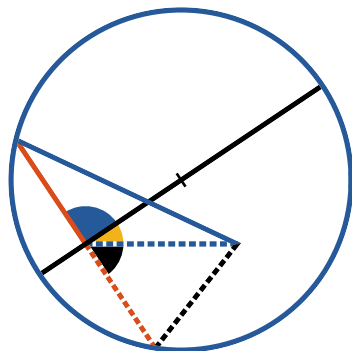
Draw within the circle any straight line , make  = , draw  \perp ; bisect , and the point of bisection is the centre.

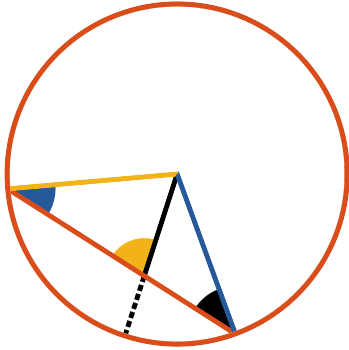
For, if it be possible, let any other point as the point of concourse of ,  and  be the centre.

Because in  and   =  (hyp. and def. I.15),  =  (const.) and  common,  =  (prop. I.8), and are therefore right angles; but  =  (const.)

 =  (ax. I.11) which is absurd; therefore the assumed point is not the centre of the circle; and in the same manner it can be proved that no other point which is not on  is the centre, therefore the centre is in , and therefore the point where  is bisected is the centre.

Q. E. D.





STRAIGHT line (—) joining two points



in the circumference of a circle (○), lies




wholly within the circle.

Find the centre of (○) (prop. III.1);

from the centre draw — to any point in —, meeting the circumference from the centre;

draw — and —.

Then  =  (prop. I.5)

but  >  or >  (prop. I.16)

∴ — > — (prop. I.19)

but — = —, ,

∴ — > —;

∴ — < —;

∴ every point in — lies within the circle.

Q. E. D.

IF a straight line (—) drawn through the centre of a circle (○) bisect a chord (---) which does not pass through the centre, it is perpendicular to it; or, if perpendicular to it, it bisects it.

Draw — and — to the centre of the circle.

In  and 

— = —, — common,

and — = --- \therefore  =  (prop. I.8)

and \therefore — \perp --- (def. I.10)

Again let — \perp ---

Then in  and 

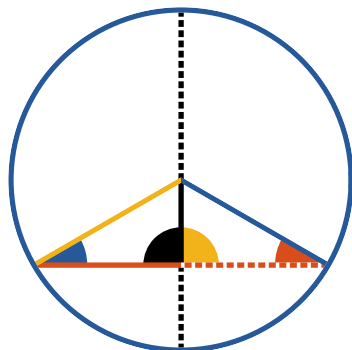
 =  (prop. I.5)

 =  (hyp.)

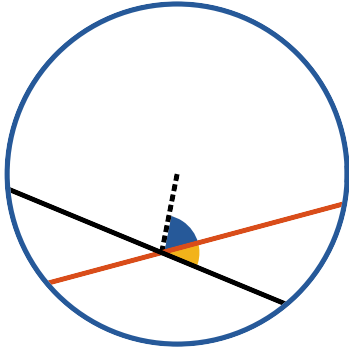
and — = —

\therefore — = --- (prop. I.26)

and \therefore — bisects ---.



Q. E. D.



In a circle two straight lines cut one another, which do not both pass through the centre, they do not bisect one another.

If one of the lines pass through the centre, it is evident that it cannot be bisected by the other, which does not pass through the centre.

But if neither of the lines ——— or ——— pass through the centre, draw from the centre to their intersection.

If ——— be bisected, \perp to it (prop. III.3)

$$\therefore \text{blue sector} = \text{yellow sector}$$

and if ——— be bisected, \perp ———
(prop. III.3)

$$\therefore \text{blue sector} = \text{yellow sector};$$

$$\text{and } \therefore \text{blue sector} = \text{yellow sector};$$

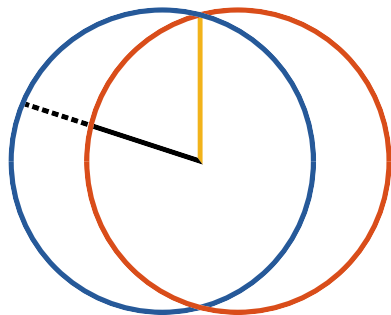
a part equal to the whole, which is absurd:

\therefore ——— and ——— do not bisect one another.

Q. E. D.



If two circles intersect, they have not the same centre.



Suppose it possible that two intersecting circles have a common centre; from such supposed centre draw — to the intersecting point, and — meeting the circumferences of the circles.

Then — = — (def. I.15)

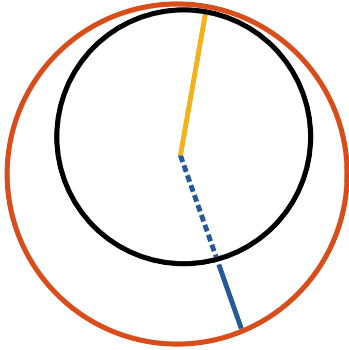
and — = — (def. I.15)

\therefore — = —

a part equal to the whole, which is absurd:



\therefore circles supposed to intersect in any point cannot have the same centre.

Q. E. D.




If two circles touch one another internally, they have not the same centre.



For, if it be possible, let both circles have the same centre; from such a supposed centre draw , and  to the point of contact.

Then  =  (def. I.15)

and  =  (def. I.15)

\therefore  = ;






a part equal to the whole, which is absurd; therefore the assumed point is not the centre of both circles, and in the same manner it can be demonstrated that no other point is.

Q. E. D.



From any point within a circle



which is not the centre, lines {    are drawn to the circumference; the greatest of those lines is that () which passes through the centre, and the least is the remaining part () of the diameter.



Of the others, that () which is nearer to the line passing through the centre, is greater than that () which is more remote.






















Fig. 2. The two lines ( and ) which make equal angles with that passing through the centre, on opposite sides of it, are equal to each other; and there cannot be drawn a third line equal to them, from the same point to the circumference.

Figure I.

To the centre of the circle draw  and ; then  =  (def. I.15)
 =  +  >  (prop. I.20)
 in like manner  may be shown to be greater than , or any other line drawn from the same point to the circumference. Again, by (prop. I.20)
 +  >  =  + ,
 take  from both; \therefore  > 
 (ax. I.3), and in like manner it may be shown that  is less than any other line drawn from the

same point to the circumference. Again, in












and ,  common,  > , and
 =  \therefore  >  (prop. I.24)
 and  may in like manner to be proved greater than any other line drawn from the same point to the

Fig. 1

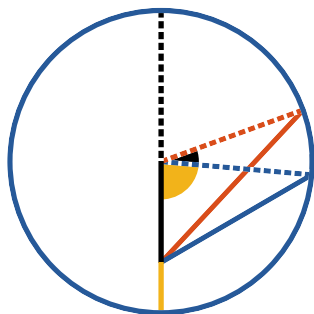
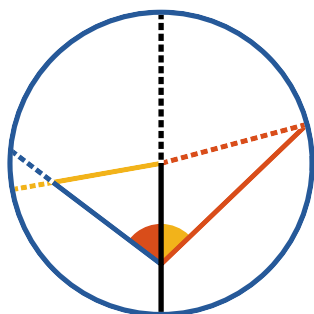


Fig. 2


























circumference more remote from .

Figure II.

If  =  then  = ,
 if not take  =  draw 
 then in  and ,  common,
 =  and  = 
 \therefore  =  (prop. I.4)
 \therefore  =  = 
 a part equal to the whole, which is absurd:

\therefore  = ; and no other line is equal to
 drawn from the same point to the circumference;
 for if it were nearer to the one passing through the centre
 it would be greater, and if it were more remote it would
 be less.

Q. E. D.



THE original text of this proposition is here divided into three parts.

I.

If from a point without a circle, straight lines $\left\{ \begin{array}{l} \text{---} \\ \text{---} \\ \text{---} \end{array} \right\}$ are drawn to the circumference; of those falling upon the concave circumference the greatest is that (---) which passes through the centre, and the line (---) which is nearer the greatest is greater than that (---) which is more remote.

Draw --- and --- to the centre.

Then, --- which passes through the centre, is greatest;

for since --- = ---, if --- be added to both

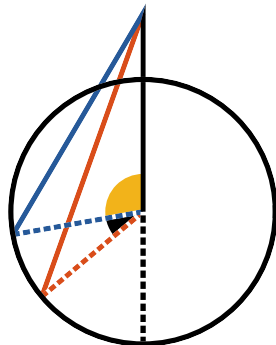
--- = --- + ---; but > --- (prop. I.20)

\therefore --- is greater than any other line drawn from the same point to the concave circumference.

Again in  and , --- = ---, and --- common,

but  > , \therefore --- > --- (prop. I.24);

and in like manner --- may be shown > than any other line more remote from ---.



II.

Of those lines falling on the convex circumference the least is that (-----) which being produced would pass through the centre, and the line which is nearer to least is less than that which is more remote.

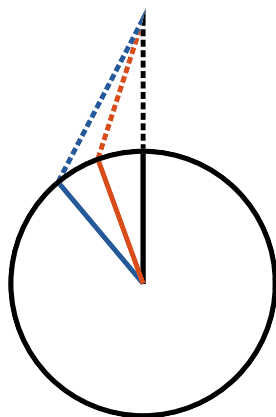
For, since --- + ----- > --- (prop. I.20)

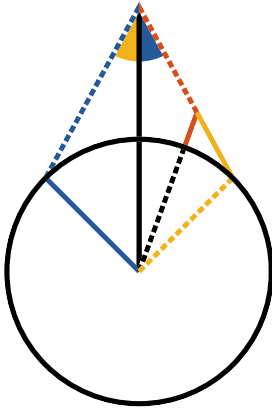
and --- = ---, \therefore ----- > ----- (ax. I.5)

And again, since --- + ----- > --- + -----

(prop. I.21), and --- = ---,

\therefore ----- < ----- . And so of others.





III.

Also the lines making equal angles with that which passes through the centre are equal, whether falling on the concave or convex circumference; and no third line can be drawn equal to them from the same point to the circumference.

For if $\text{---} > \text{---}$, but making $\triangle = \triangle$;
make $\text{---} = \text{---}$, and draw --- .

Then in \triangle and \triangle we have $\text{---} = \text{---}$

and --- common, and also $\triangle = \triangle$,

$\therefore \text{---} = \text{---}$ (prop. I.4);

but $\text{---} = \text{---}$;

$\therefore \text{---} = \text{---}$, which is absurd.

$\therefore \text{---}$ is $\neq \text{---}$, nor to any part of --- ,





$\therefore \text{---}$ is $\neq \text{---}$.

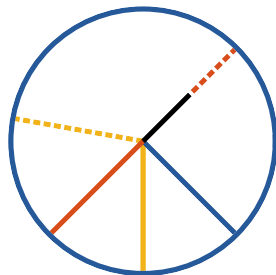
Neither is $\text{---} > \text{---}$, they are $\therefore =$ to each other.




And any other line drawn from the same point to the circumference must lie at the same side with one of these lines, and be more or less remote than it from the line passing through the centre, and cannot therefore be equal to it.









Q. E. D.




If a point be taken within a circle , from which more than two equal straight lines (, , ) can be drawn to the circumference, that point must be the centre of the circle.

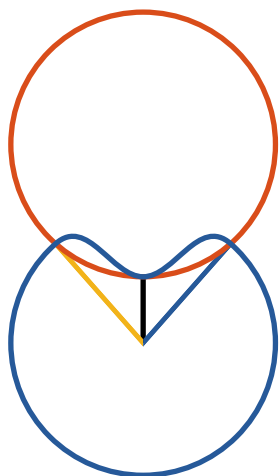
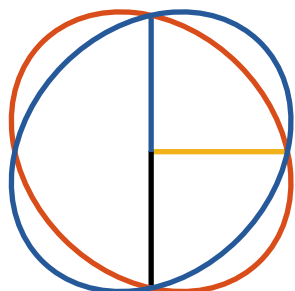




For if it be supposed that the point  in which more than two equal straight lines meet is not the centre, some other point  must be; join these two points by  and produce it both ways to the circumference.





Then since more than two equal straight lines are drawn from a point which is not the centre, to the circumference, two of them at least must lie at the same side of the diameter ; and since from a point , which is not the centre, straight lines are drawn to the circumference; the greatest is , which passes through the centre: and  which is nearer to , >  which is more remote (prop. III.8); but  =  (hyp.) which is absurd.




The same may be demonstrated of any other point, different from , which must be the centre of the circle.





Q. E. D.





NE circle  cannot intersect another  in more points than two.

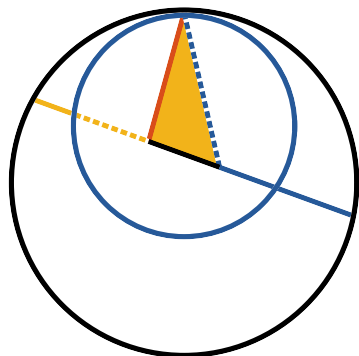
For, if it be possible, let it intersect in three points; from the centre of  draw ,  and  to the points of intersection;






\therefore  =  =  (def. I.15), but as the circles intersect, they have not the same centre (prop. III.5):





\therefore the assumed point is not the centre of , and \therefore as ,  and  are drawn from a point not the centre, they are not equal (prop. III.7 and III.8); but it was shown before that they were equal, which is absurd; the circles therefore do not intersect in three points.

Q. E. D.

I F two circles  and  touch one another internally, the right line joining their centres, being produced, shall pass through a point of contact.



For, if it be possible, let  join their centres, and produce it both ways; from a point of contact draw  to the centre of , and from the same point of contact draw  to the centre of .


Because in ;  +  > 

(prop. I.20),

and  =   as they are radii of






but  +  >  ;

take away  which is common,

and  > ;

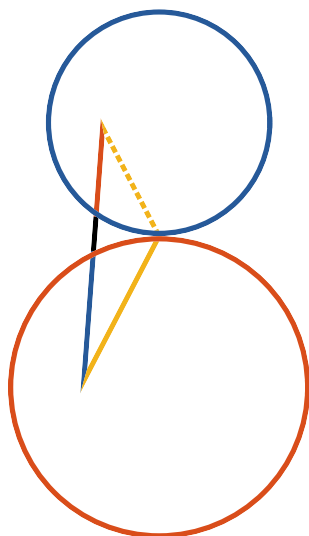
but  = ,




because they are radii of ,

and \therefore  >  a part greater than the whole, which is absurd.

The centres are not therefore so placed, that a line joining them can pass through any point but a point of contact.

Q. E. D.



I F two circle  and  touch one another externally, the straight line  joining their centres, passes through the point of contact.

If it be possible, let  joining the centres, and not pass through a point of contact; then from a point of contact draw  and  to the centres.

\therefore  +  >  (prop. I.20)

and  =  (def. I.15),

and  =  (def. I.15),

\therefore  +  > ,

a part greater than the whole, which is absurd.




The centres are not therefore so placed, that the line joining them can pass through any point but the point of contact.

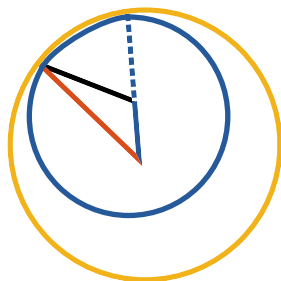
Q. E. D.



NE circle cannot touch another, either externally or internally, in more points than one

Figure I.

For, if it possible, let  and  touch one another internally in two points; draw  joining their centres, and produce it until it pass through one of the points of contact (prop. III.11);










draw  and .
 But  =  (def. I.15),
 \therefore if  be added to both,
 $\text{---} = \text{---} + \text{---}$;
 but  =  (def. I.15),
 and $\therefore \text{---} + \text{---} = \text{---}$;
 but $\therefore \text{---} + \text{---} > \text{---}$ (prop. I.20),
 which is absurd.

Figure II.

But if the points of contact be the extremities of the right line joining the centres, this straight line must be bisected in two different points for the two centres; because it is the diameter of both circles, which is absurd.

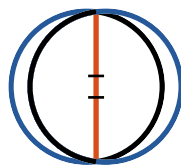
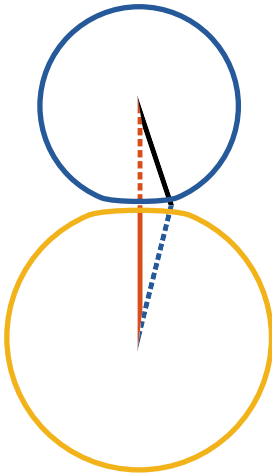





Figure III.



Next, if it be possible, let



and

touch externally in two points; draw  joining the centres of the circles, and passing through one of the points of contact, and draw  and .

 =  (def. I.15);

and  =  (def. I.15);


\therefore  +  = .

but  +  >  (prop. I.20), which is absurd.

There is therefore no case in which two circles can touch one another in two points.

Q. E. D.

E

QUAL straight lines () inscribed in a circle are equally distant from the centre; and also, straight lines equally distant from the centre are equal.

From the centre of  draw  \perp to 

and  \perp , join  and .

Then  = half  (prop. III.3)

and  = $\frac{1}{2}$  (prop. III.3),

since  =  (hyp.)

$$\therefore \text{img alt="yellow solid line" data-bbox="245 340 285 350"/> = \text{img alt="red solid line" data-bbox="355 340 395 350"},$$

and  =  (def. I.15)

$$\therefore \text{img alt="black solid line" data-bbox="225 380 265 390"}^2 = \text{img alt="blue solid line" data-bbox="375 380 415 390"}^2;$$

but since  is a right angle







$$\text{img alt="black solid line" data-bbox="155 435 195 445"}^2 = \text{img alt="black dashed line" data-bbox="245 435 285 445"}^2 + \text{img alt="red solid line" data-bbox="385 435 425 445"}^2 \text{ (prop. I.47)}$$

and  $^2 = \text{img alt="blue dashed line" data-bbox="285 455 325 465"}^2 + \text{img alt="yellow solid line" data-bbox="425 455 465 465"}^2$ for the same reason,

$$\therefore \text{img alt="black dashed line" data-bbox="165 480 205 490"}^2 + \text{img alt="red solid line" data-bbox="305 480 345 490"}^2 = \text{img alt="blue dashed line" data-bbox="285 480 325 490"}^2 + \text{img alt="yellow solid line" data-bbox="425 480 465 490"}^2$$

$$\therefore \text{img alt="black dashed line" data-bbox="255 505 295 515"}^2 = \text{img alt="blue dashed line" data-bbox="335 505 375 515"}^2$$

$$\therefore \text{img alt="black dashed line" data-bbox="255 525 295 535"/> = \text{img alt="blue dashed line" data-bbox="335 525 375 535}$$

Also, if the lines  and  be equally distant from the centre; that is to say, if the perpendiculars  and  be given equal, then  = .

For, as in the preceding case,

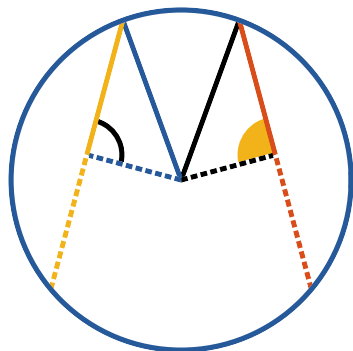
$$\text{img alt="blue dashed line" data-bbox="175 665 215 675"}^2 + \text{img alt="yellow solid line" data-bbox="255 665 295 675"}^2 = \text{img alt="red solid line" data-bbox="385 665 425 675"}^2 + \text{img alt="black dashed line" data-bbox="445 665 485 675"}^2$$

$$\text{but } \text{img alt="blue dashed line" data-bbox="245 690 285 700"}^2 = \text{img alt="black dashed line" data-bbox="345 690 385 700"}^2$$

$$\therefore \text{img alt="yellow solid line" data-bbox="105 715 145 725"/> = \text{img alt="red solid line" data-bbox="245 715 285 725"}, \text{ and the doubles of these } \text{img alt="red dashed line" data-bbox="485 715 525 725}$$

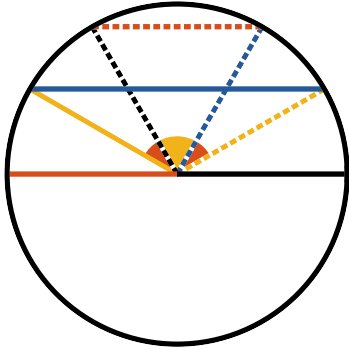
and  are also equal.



Q. E. D.









THE diameter is the greatest straight line in a circle: and, of all others, that which is nearest to the centre is greater than the more remote.




Figure I.








The diameter  is $>$ any line .



For draw  and .





Then  = 
and  = ,





\therefore  +  = 





but  +  $>$  (prop. I.20)
 \therefore  $>$ .



Again, the line which is nearer the centre is greater than the one more remote.

First, let the given lines be  and , which are at the same side of the centre and do not intersect;

draw    ;

In  and  and  ,

 and  =  and ;

but  $>$ ,













\therefore  $>$  (prop. I.24)

Figure II.

Let the given lines be  and  which either are at different sides of the centre, or intersect; from the centre draw  and  \perp  and ,

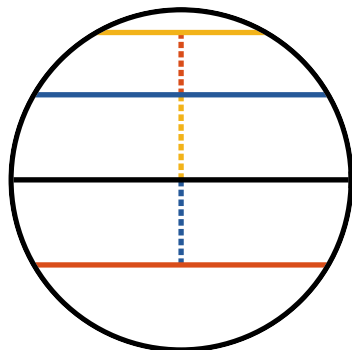
make  = ,

and draw  \perp .

Since  and  are equally distant from the centre,  =  (prop. III.14);


but  >  (prop. III.15),




\therefore  > .





Q. E. D.

T




o draw a tangent to a given circle  from a given point, either in or outside of its circumference.

If a given point be in the circumference, as at , it is plain that the straight line  \perp  the radius, will be the required tangent (prop. III.16).

But if the given point  be outside of the circumference,


draw  from it to the centre, cutting ;

and draw  \perp ,

describe  concentric with  radius = ,

draw  to the centre from the point where

 falls on  circumference,

draw  \perp  from the point where it cuts





Then  will be the tangent required.

For in  and   = , 

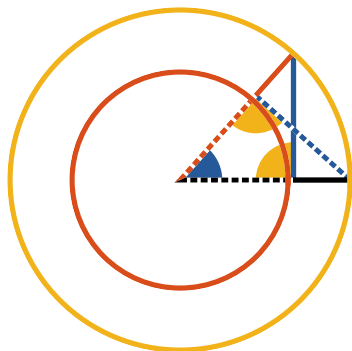
common,

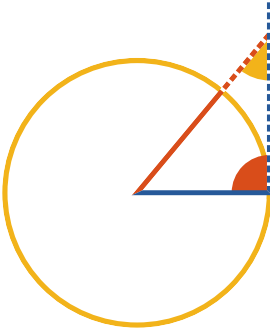
and  = ,

\therefore (prop. I.4)  =  = ,

\therefore  is a tangent to .

Q. E. D.





IF a straight line be a tangent to a circle, the straight line — drawn from the centre to the point of contact, is perpendicular to it.

For, if it be possible, let — be \perp ,

then \therefore  = ,  is acute (prop. I.17)

\therefore — > — (prop. I.19);

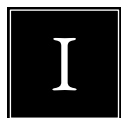
but — = —,



and \therefore — > —, a part greater than the whole,
which is absurd.



\therefore — is not \perp

and in the same manner it can be demonstrated, that no other line except — is perpendicular to

Q. E. D.







If a straight line  be a tangent to a circle, the straight line , drawn perpendicular to it from point of the contact, passes through the centre of the circle.


For, if it be possible, let the centre be without , and draw  from the supposed centre to the point of contact.

\therefore  \perp  (prop. III.18)

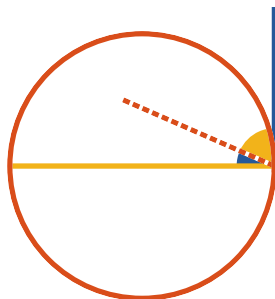
\therefore  = , a right angle;

but  =  (hyp.),

and \therefore  = , a part equal to the whole, which is absurd.

Therefore the assumed point is not the centre; and in the same manner it can be demonstrated, that no other point without  is the centre.

Q. E. D.



THE angle at the centre of a circle is double the angle at the circumference, when they have the same part of the circumference for their base.

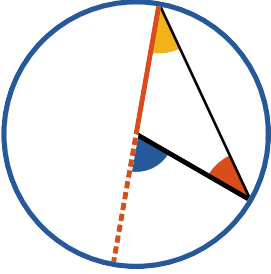



Figure I.

Let the centre of the circle be on a side of .

$$\therefore \text{—} = \text{—},$$

$$\text{yellow triangle} = \text{red triangle} \text{ (prop. I.5).}$$

$$\text{But blue sector} = \text{yellow triangle} + \text{red triangle},$$

$$\text{or blue sector} = \text{twice yellow triangle (prop. I.32).}$$

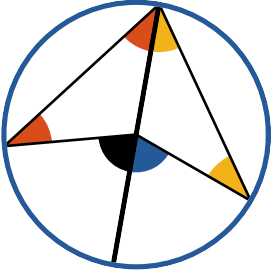






Figure II.

Let the centre be within , the angle at the circumference;

draw — from the angular point through the centre of the circle;

then  = , and  = , because of the equality of the sides (prop. I.5).



$$\text{Hence red triangle} + \text{red triangle} + \text{yellow triangle} + \text{yellow triangle} = \text{twice yellow triangle}.$$



$$\text{But black sector} = \text{red triangle} + \text{red triangle},$$



$$\text{and blue sector} = \text{yellow triangle} + \text{yellow triangle},$$



$$\therefore \text{blue sector} = \text{twice yellow triangle}.$$

Figure III.

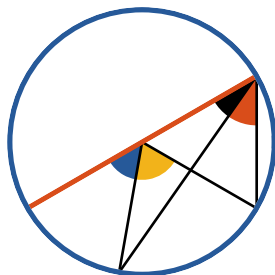
Let the centre be without 
and draw , the diameter.

\therefore  = twice ;

and  = twice  (case I.);

\therefore  = twice .

Q. E. D.





THE angles in the same segment of a circle are equal.

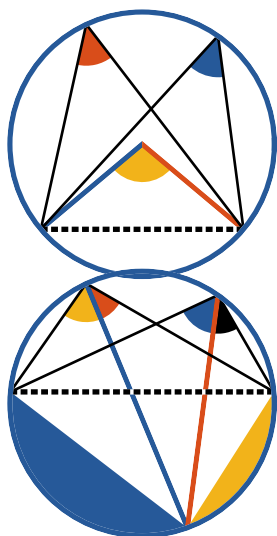






Figure I.

Let the segment be greater than a semicircle, and draw  and  to the centre.

$$\text{yellow sector} = \text{twice } \text{red angle} \text{ or twice } = \text{blue angle} \text{ (prop. III.20);}$$

$$\therefore \text{red angle} = \text{blue angle}$$

Figure II.





Let the segment be a semicircle, or less than a semicircle, draw  the diameter, also draw .



$$\text{yellow sector} = \text{blue angle} \text{ and } \text{red angle} = \text{black angle} \text{ (case I.)}$$

$$\therefore \text{yellow sector} = \text{blue angle} + \text{black angle}$$

Q. E. D.



THE opposite angles  and ,  and  of any quadrilateral figure inscribed in a circle, are together equal to two right angles.

Draw  and  the diagonals;
and because angles in the same segment are equal

$$\text{blue sector} = \text{blue sector},$$

$$\text{and } \text{red sector} = \text{red sector};$$

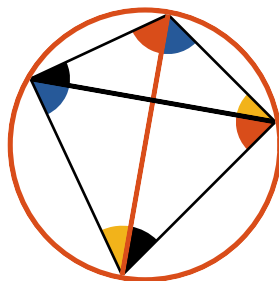
add  to both.

$$\text{blue sector} + \text{yellow sector} = \text{yellow sector} + \text{blue sector} + \text{red sector} = \text{two right angles}$$

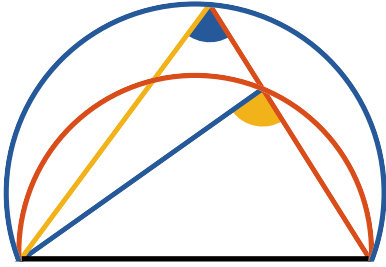
(prop. I.32).

In like manner it may be shown that,

$$\text{blue sector} + \text{red sector} = \text{semicircle}.$$



Q. E. D.



UPON the same straight line, and upon the same side of it, two similar segments of circles cannot be constructed, which do not coincide.

For if it be possible, let two similar segments




and



be constructed;

draw any right line  cutting both the segments,

draw  and .

Because the segments are similar,



(def. III.11),





but  >  (prop. I.16)

which is absurd;







therefore no point in either of the segments falls without the other, and therefore the segments coincide.






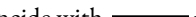
Q. E. D.



*S*IMILAR segments  and ,
of circles upon equal straight lines ( and ) are each equal to the other.

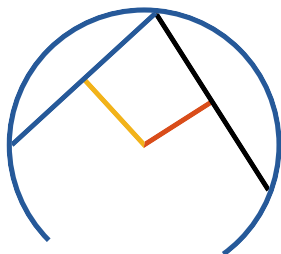


For, if  be so applied to ,
that  may fall on ,
the extremities of  may be on the extremities








and  at the same side as ;
 \therefore  = ,
 must wholly coincide with ;




and the similar segments being then upon the same straight line and at the same side of it, must also coincide (prop. III.23), and are therefore equal.

Q. E. D.







SEGMENT *of a circle being given, to describe the circle of which it is the segment.*





From any point in the segment draw  and ,
bisect them, and from the points of bisection
draw  \perp 
and  \perp 
where they meet is the centre of the circle.

Because  terminated in the circle is bisected perpendicularly by , it passes through the centre (prop. III.1), likewise  passes through the centre, therefore the centre is in the intersection of these perpendiculars.

Q. E. D.





I

N equal circles  and , the arcs ,  on which stand equal angles, whether at the centre of circumference, are equal.

For, let  =  at the centre,
draw  and .

Then since  = ,

 and  have

 =  =  = ,

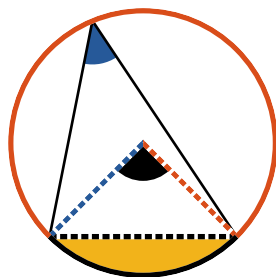
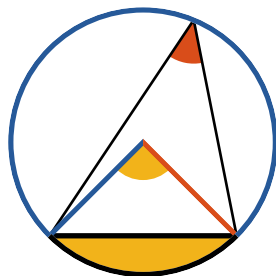
and  = ,

\therefore  =  (prop. I.4).

But  =  (prop. III.20);

\therefore  and  are similar (def. III.11);

they are also equal (prop. III.24)



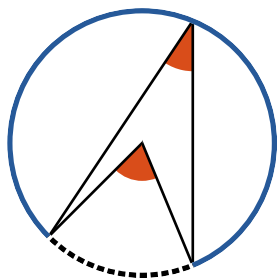
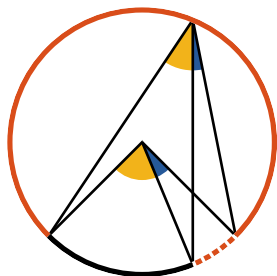
If therefore the equal segments be taken from the equal circles, the remaining segments will be equal;





hence  =  (ax. I.3);

and \therefore  = .



But if the given equal angles be at the circumference, it is evident that the angles at the centre, being double of those at the circumference, are also equal, and therefore the arcs on which they stand are equal.

Q. E. D.





IN equal circles  and  the angles  and  which stand upon equal arches are equal, whether they be at the centres or at the circumferences.



For if it be possible, let one of them

 be greater than the other 

and make  = 

\therefore  =  (prop. III.26)





but  =  (hyp.)





\therefore  =  a part equal to the whole,
which is absurd;


\therefore neither angle is greater than the other,
and \therefore they are equal.



Q. E. D.

I

N equal circles  and ,
equal chords ,  cut off equal
arches.

From the centres of the equal circles,
draw ,  and , ;

and \therefore  = 

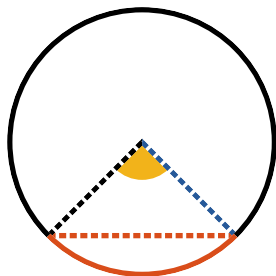
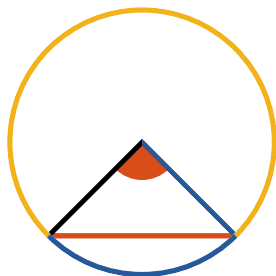
,  = , 

also  =  (hyp.)

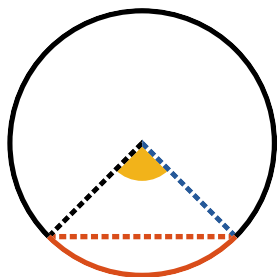
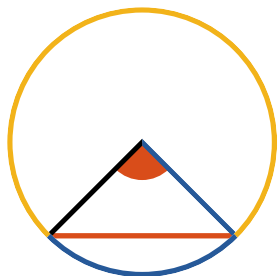
\therefore  = 





\therefore  =  (prop. III.26)

and \therefore  =  (ax. I.3).







Q. E. D.



IN equal circles  and  the
chords  and  which subtend
equal arcs are equal.

If the equal arcs be semicircles the proposition is evident.

But if not,

let ,  and ,  be drawn to
the centres;

\therefore  =  (hyp.)

and  =  (prop. III.27);


but  and  =  and 

















\therefore  =  (prop. I.4);

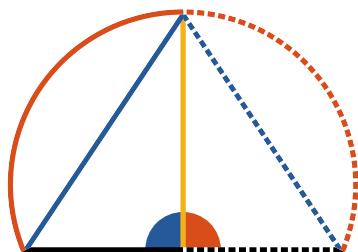
but these are the chords subtending the equal arcs.

Q. E. D.



o bisect a given arc 

Draw ;
 make  = ,
 draw  \perp , and it bisects the arc.
 Draw  and .
 =  (const.)
 is common,
 and  =  (const.)
 \therefore  =  (prop. I.4)
 =  (prop. III.28),
 and therefore the given arc is bisected.



Q. E. D.

IN a circle the angle in a semicircle is a right angle, the angle in a segment greater than a semicircle is acute, and the angle in a segment less than a semicircle is obtuse.

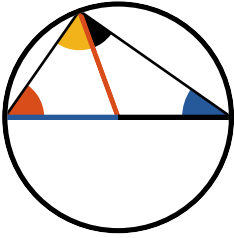







Figure I.

The angle  in a semicircle is a right angle.

Draw  and .

 =  and  =  (prop. I.5)

 +  =  = the half of  = 
(prop. I.32)

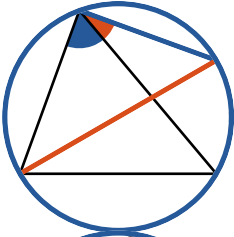







Figure II.

The angle  in a segment greater than a semicircle is acute

Draw  the diameter, and .

\therefore  = a right angle, \therefore  is acute.

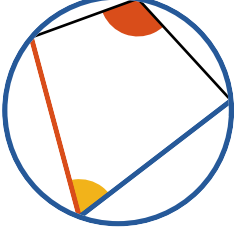









Figure III.

The angle  in a segment less than a semicircle is obtuse.



Take in the opposite circumference any point, to which

draw  and .



\therefore  +  =  (prop. III.22)

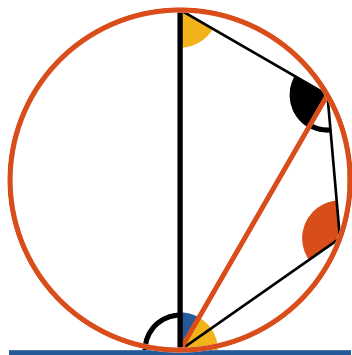
but  <  (figure II.), \therefore  is obtuse.

Q. E. D.

I F a right line — be a tangent to a circle, and from the point of contact a right line — be drawn cutting the circle, the angle  made by this line with the tangent is equal to the angle  in the alternate segment of the circle.

If the chord should pass through the centre, it is evident the angles are equal, for each of them is a right angle. (prop. III.16 and III.31)

But if not, draw  \perp  from the point of contact, it must pass through the centre of the circle, (prop. III.19)



$$\therefore \text{black sector} = \text{white sector} \quad (\text{prop. III.31})$$

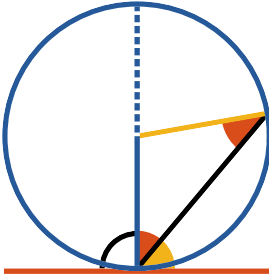
$$\text{yellow sector} + \text{blue sector} = \text{white sector} = \text{yellow sector} + \text{red sector} \quad (\text{prop. I.32})$$




$$\therefore \text{yellow sector} = \text{yellow sector} + \text{red sector} \quad (\text{ax. I.3}).$$

$$\text{Again } \text{white sector} + \text{yellow sector} = \text{white sector} = \text{yellow sector} + \text{red sector} \quad (\text{prop. III.22})$$

$$\therefore \text{white sector} + \text{blue sector} = \text{red sector}, \quad (\text{ax. I.3}), \text{ which is the angle in the alternate segment.}$$







Q. E. D.






O *N a given straight line — to describe a segment of a circle that shall contain an angle equal to a given angle* , , .






If a given angle be a right angle, bisect the given line, and describe a semicircle on it, this will evidently contain a right angle. (prop. III.31)

If the given angle be acute or obtuse, make with the given line, at its extremity,

 = ,
draw  \perp 
and make  = ,



describe  with  or  as radius, for they are equal.

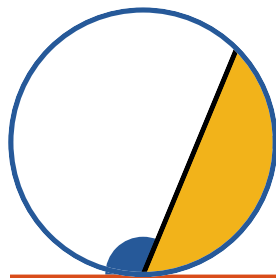
 is tangential to  (prop. III.16)


\therefore  divides the circle into two segments capable of containing angles equal to  and  which were made respectively equal to  and  (prop. III.32).



Q. E. D.




To cut off from a given circle  a segment which shall contain an angle equal to a given angle .



Draw  (prop. III.17), a tangent to the circle at any point;

at the point of contact make  =  the given angle;

and  contains an angle = the given angle.

Because  is a tangent,
and  cuts it,

the angle in  =  (prop. III.32),

but  =  (const.).

Q. E. D.







IF two chords {  } in a circle intersect each other, the rectangle contained by the segments of the one is equal to the rectangle contained by the segments of the other.

Figure I.

If the given right lines pass through the centre, they are bisected in the point of intersection, hence the rectangles under their segments are squares of their halves, and therefore equal.

Figure II.


Let   pass through the centre, and  not; draw  and .

Then $\text{blue} \times \text{dotted blue} = \text{yellow}^2 - \text{dotted red}^2$ (prop. II.6), or

$$\text{blue} \times \text{dotted blue} = \text{dotted red}^2 - \text{red}^2.$$

$\therefore \text{blue} \times \text{dotted blue} = \text{dotted red} \times \text{red}$ (prop. II.5).

Figure III.

Let neither of the given lines pass through the centre, draw through their intersection a diameter ,

and $\text{dotted red} \times \text{red} = \text{blue} \times \text{dotted blue}$ (part 2.),

also $\text{dotted red} \times \text{red} = \text{black} \times \text{dotted black}$ (part 2.);

$\therefore \text{blue} \times \text{dotted blue} = \text{black} \times \text{dotted black}.$

Q. E. D.

I *F* from a point without a circle two straight lines be drawn to it, one of which — is a tangent to the circle, and the other — cuts it; the rectangle under the whole cutting line — and the external segment — is equal to the square of the tangent —.

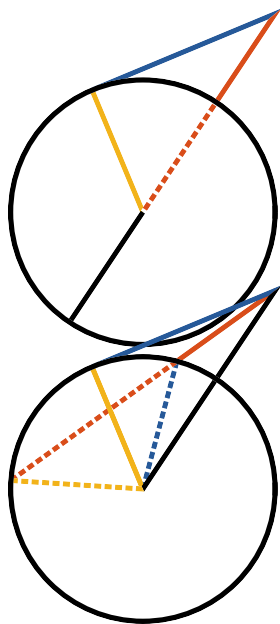
Figure I.

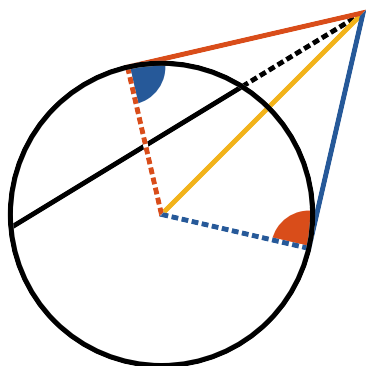
Let — pass through the centre;
 draw — from the centre to the point of contact;
 $\text{—}^2 = \text{—}^2 - \text{—}^2$ (prop. I.47),
 or $\text{—}^2 = \text{—}^2 - \text{—}^2$,
 $\therefore \text{—}^2 = \text{—} \times \text{—}$ (prop. II.6).

Figure II.

If — do not pass through the centre,
 draw — and —.
 Then $\text{—} \times \text{—} = \text{—}^2 - \text{—}^2$
 (prop. II.6),
 that is, $\text{—} \times \text{—} = \text{—}^2 - \text{—}^2$,
 $\therefore \text{—} \times \text{—} = \text{—}^2$ (prop. III.18).

Q. E. D.





IF from a point outside of a circle two straight lines be drawn, the one ———— cutting the circle, the other ———— meeting it, and if the rectangle contained by the whole cutting line ———— and its external segment ———— be equal to the square of the line meeting the circle, the latter ———— is a tangent to the circle.

Draw from the given point ————, a tangent to the circle,

and draw from the centre ————, ————, and ————,

$$\text{—————}^2 = \text{—————} \times \text{—————} \text{ (prop. III.36)}$$

$$\text{but } \text{—————}^2 = \text{—————} \times \text{—————} \text{ (hyp.)},$$

$$\therefore \text{—————}^2 = \text{—————}^2,$$

$$\text{and } \therefore \text{—————} = \text{—————}.$$

Then in  and  and

$$\text{—————} \text{ and } \text{—————} = \text{—————} \text{ and } \text{—————},$$

and ———— is common,

$$\therefore \text{—————} = \text{—————} \text{ (prop. I.8);}$$

$$\text{but } \text{—————} = \text{—————} \text{ a right angle (prop. III.18),}$$

$$\therefore \text{—————} = \text{—————} \text{ a right angle,}$$

and \therefore ———— is a tangent to the circle (prop. III.16).

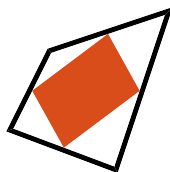
Q. E. D.

Book IV

Definitions

IV.1

A rectilinear figure is said to be *inscribed in* another, when all the angular points of the inscribed figure are on the sides of the figure in which it is said to be inscribed.



IV.2

A figure is said to be *described about* another figure, when all the sides of the circumscribed figure pass through the angular points of the other figure.

IV.3

A rectilinear figure is said to be *inscribed in* a circle, when the vertex of each angle of the figure is in the circumference of the circle.



IV.4

A rectilinear figure is said to be *circumscribed about* a circle, when each of its sides is a tangent to the circle.



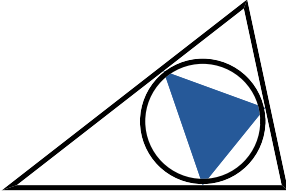
IV.5

A circle is said to be *inscribed in* a rectilinear figure, when each side of the figure is a tangent to the circle.



IV.6

A circle is said to be *circumscribed about* a rectilinear figure, when the circumference passes through the vertex of each angle of the figure.



is circumscribed.

IV.7



A straight line is said to be *inscribed in* a circle, when its extremities are in the circumference.







The Fourth Book of the Elements is devoted to the solution of problems, chiefly relating to the inscription and circumscription of regular polygons and circles.



A regular polygon is one whose angles and sides are equal.

I


In a given circle  to place a straight line, equal to a given straight line () , not greater than the diameter of the circle.

Draw , the diameter of ;

and if  = , then the problem is solved.


But if  be not equal to ,

 >  (hyp.);

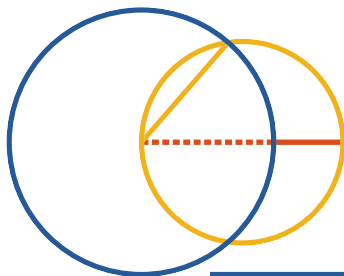
make  =  (prop. I.3)

with  as radius,

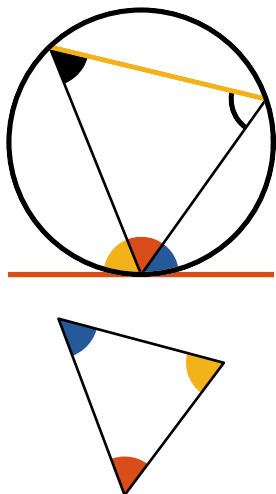
describe , cutting ,


and draw , which is the line required.


For  =  =  (prop. I.15
and const.).








Q. E. D.



I *N* a given circle  to inscribe a triangle
equiangular to a given triangle.

To any point of the given circle draw , a tangent
(prop. III.17);

and at the point of contact make  = 
(prop. I.23)

and in like manner  = ,
and draw .

\therefore  =  (const.)

and  =  (prop. III.32)

\therefore  = ;

also  =  for the same reason.

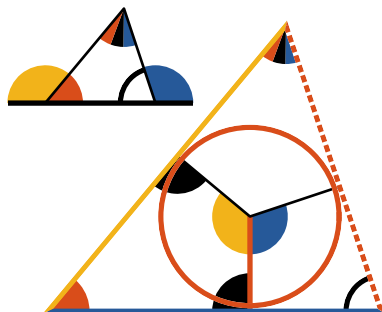
\therefore  =  (prop. I.32),


and therefore the triangle inscribed in the circle is equian-
gular to the given one.


Q. E. D.



ABOUT a given circle  to circumscribe a triangle equiangular to a given triangle.







Produce any side , of the given triangle both ways;



from the centre of the given circle draw , any radius.

Make  =  (prop. I.23)

and  = .





At the extremities of the radii, draw , , and , tangents to the given circle. (prop. III.17)

The four angles of , taken together are equal to four right angles. (prop. I.32)



but  and  are right angles (const.)

\therefore  +  = , two right angles

but  =  (prop. I.13)

and  =  (const.) and \therefore  = .

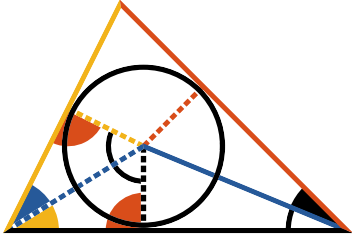
In the same manner it can be demonstrated that

 = .











\therefore  =  (prop. I.32)

and therefore the triangle circumscribed about the given circle is equiangular to the given triangle.

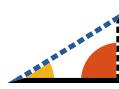
Q. E. D.



In a given triangle  to inscribe a circle.








Bisect  and  (prop. I.9) by  and ; from the point where these lines meet draw ,  and  respectively perpendicular to ,  and .

In



and



 = ,  =  and  common,
 \therefore  =  (prop. I.4 and I.26).

In like manner, it may be shown also that

 = ,
 \therefore  =  = .

hence with any one of these lines as radius, describe










and it will pass through the extremities of the other two; and the sides of the given triangle, being perpendicular to the three radii at their extremities, touch the circle (prop. III.16), which is therefore inscribed in the given triangle.

Q. E. D.



To describe a circle about a given triangle.

Make  =  and  = 
(prop. I.10)

From the points of bisection draw  and  \perp  and  respectively (prop. I.11), and from their point of concurrence draw ,  and  and describe a circle with any one of them, and it will be the circle required.





 =  (const.),




 common,

 =  (const.),

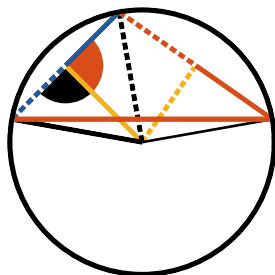
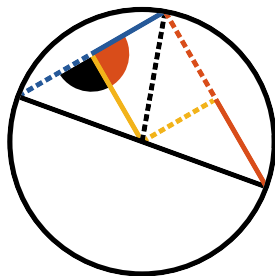
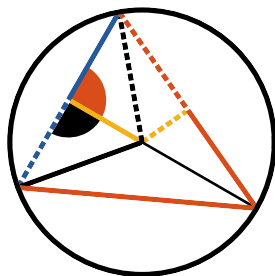
\therefore  =  (prop. I.4).

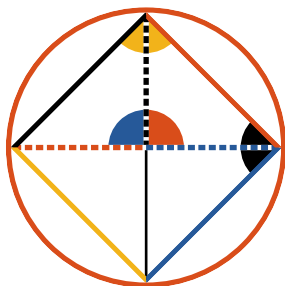
In like manner it may be shown that

 = .





\therefore  =  = ; and therefore a circle described from the concurrence of these three lines with any one of them as a radius will circumscribe the given triangle.

Q. E. D.









N a given circle  to inscribe a square.

Draw the two diameters of the circle \perp to each other, and draw , ,  and .



is a square.

For, since  and  are, each of them, in a semicircle, they are right angles (prop. III.31),

\therefore  \parallel  (prop. I.28):


and in like manner  \parallel .


And \therefore  =  (const.),

and  =  =  (def. I.15).

\therefore  =  (prop. I.4);

and since the adjacent sides and angles of the parallelogram





 are equal, they are all equal (prop. I.34);

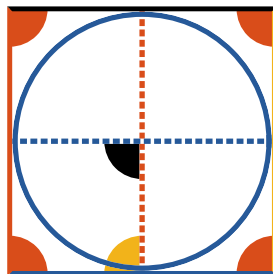
and \therefore , inscribed in the given circle, is a square.

Q. E. D.







ABOUT a given circle  to circumscribe a square.





Draw two diameters of the given circle perpendicular to each other, and through their extremities draw , ,  and  tangents to the circle;




and  is a square.

 =  a right angle, (prop. III.18)





also  =  (const.),

\therefore  \parallel ; in the same manner it can be demonstrated that  \parallel , and also that

 and  \parallel ;

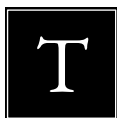
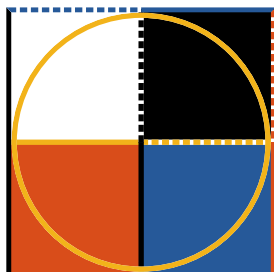
\therefore  is a parallelogram,

and \therefore  =  =  =  =  they are all right angles (prop. I.34);









it is also evident that , ,  and  are equal.





\therefore  is a square.




Q. E. D.



o *inscribe a circle in a given square.*

Make  = ,
 and  = ,
 draw  || ,
 and  || 
 (prop. I.31)

 \therefore  is a parallelogram;
 and since  =  (hyp.)

 = 
 \therefore  is equilateral (prop. I.34)

In like manner it can be shown that




are equilateral parallelograms;

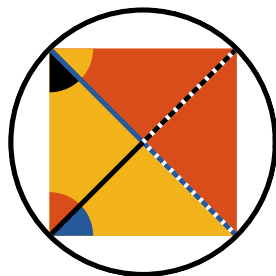
\therefore  =  =  = .

and therefore if a circle be described from the concurrence of these lines with any one of them as radius, it will be inscribed in the given square (prop. III.16).

Q. E. D.




o describe a circle about a given square .




Draw the diagonals  and  intersecting each other;

then, because  and  have their sides equal, and the base  common to both,

 =  (prop. I.8),

or  is bisected:


in like manner it can be shown that  is bisected;

but  = ,

hence  =  their halves,

\therefore  =  (prop. I.6);

and in like manner it can be proved that

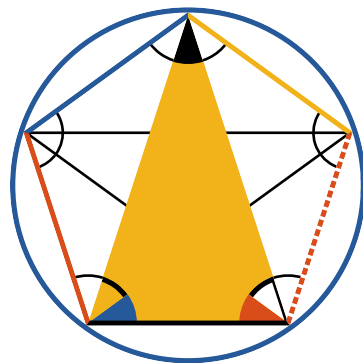
 =  =  = .

If from the confluence of these lines with any one of them as radius, a circle be described, it will circumscribe the given square.


Q. E. D.













N a given circle  to inscribe an equilateral and equiangular pentagon.



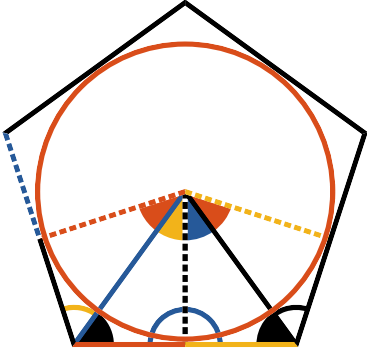
Construct an isosceles triangle, in which each of the angles at the base shall be double of the angle at the vertex,


and inscribe in the given circle a triangle  equiangular to it (prop. IV.2);


Bisect  and  (prop. I.9),
draw , ,  and .

Because each of the angles , , ,  and  are equal, the arcs upon which they stand are equal (prop. III.26); and \therefore , , ,  and  which subtend these arcs are equal (prop. III.29) and \therefore the pentagon is equilateral, it is also equiangular, as each of its angles stand upon equal arcs (prop. III.27).

Q. E. D.



To describe an equilateral and equiangular pentagon about a given circle .




Draw five tangents through the vertices of the angles of any regular pentagon inscribed in the given circle  (prop. III.17).

These five tangents will form the required pentagon.





Draw .

In  and 





 =  (prop. I.47)

 = , and  common;

\therefore  =  and \therefore  =  (prop. I.8)

\therefore  = twice , and  = twice .





In the same manner it can be demonstrated that

 = twice , and  = twice .

but  =  (prop. III.27),



\therefore their halves  = , also  = ,

and  common;

\therefore  =  and  = ,

\therefore  = twice .





In the same manner it can be demonstrated that

 = twice ,



but  = 

\therefore  = .

In the same manner it can be demonstrated that the other sides are equal, and therefore the pentagon is equilateral, it is also equiangular, for

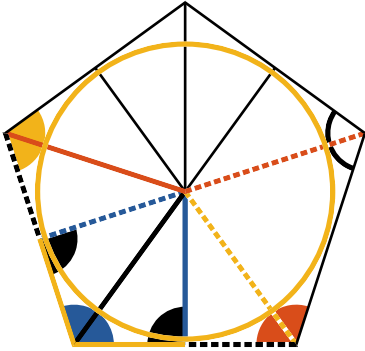
 = twice  and  = twice ,

and therefore  = ,


\therefore  = ;

in the same manner it can be demonstrated that the other angles of the described pentagon are equal.





Q. E. D.








To inscribe a circle in a given equiangular and equilateral pentagon.





Let  be a given equiangular and equilateral pentagon; it is required to inscribe a circle in it.

Make  = , and  =  (prop. I.9)

Draw , , , , etc.



\therefore  = ,  = , and  common to the two triangles





\therefore  =  and  =  (prop. I.4)




And \therefore  =  = twice 

\therefore twice , hence  is bisected by .

In like manner it may be demonstrated that  is bisected by , and that the remaining angle of the polygon is bisected in a similar manner.

Draw , , etc. perpendicular to the sides of the pentagon.


Then in the two triangles  and 

we have  =  (const.),  common,

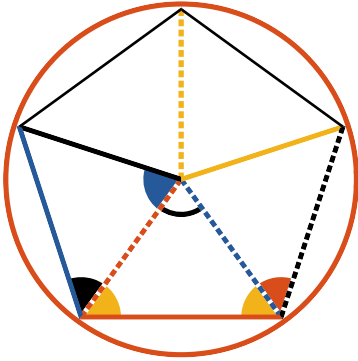
and  =  = a right angle;

\therefore  =  (prop. I.26)

In the same way it may be shown that the five perpendiculars on the sides of the pentagon are equal to one another.

Describe  with any one of the perpendiculars as radius, and it will be the inscribed circle required. For if it does not touch the sides of the pentagon, but cut them, then a line drawn from the extremity at right angles to the diameter of a circle will fall within the circle, which has been shown to be absurd (prop. III.16).

Q. E. D.






To describe a circle about a given equilateral and equiangular pentagon.

Bisect  and  by  and , and from the point of section, draw ,  and



\therefore  =  (prop. I.6);

and since in  and ,

 = , and  common,

also  = ;

\therefore  =  (prop. I.4).

In like manner it may be proved that

 =  = .

and therefore

 =  =  =  = .








Therefore if a circle be described from the point where these five lines meet, with any one of them as a radius, it will circumscribe the given pentagon.




Q. E. D.




T

o *inscribe an equilateral and equiangular hexagon in a given circle*







From any point in the circumference of the given circle describe  passing through its centre, and draw the diameters ,  and ; draw , , , etc. and the required hexagon is inscribed in the given circle.

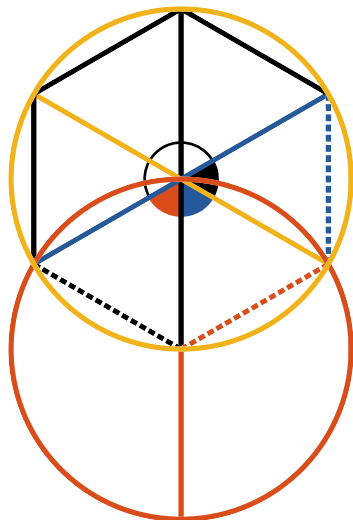
Since  passes through the centres of the circles,  and  are equilateral triangles, hence

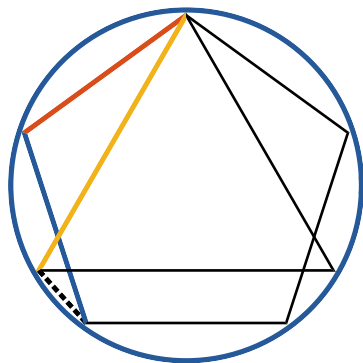
 =  = one-third of  (prop. I.32) but

 =  (prop. I.13);

\therefore  =  =  = one-third of 
(prop. I.32), and the angles vertically opposite to these are all equal to one another (prop. I.15), and stand on equal arches (prop. III.26), which are subtended by equal chords (prop. III.29); and since each of the angles of the hexagon is double of the angle of an equilateral triangle, it is also equiangular.

Q. E. D.





To inscribe a circle in an equilateral and equiangular quindecagon in a given circle.

Let — and — be the sides of an equilateral pentagon inscribed in the given circle, and — the side of an inscribed equilateral triangle.

The arc subtended by — and — $\left. \vphantom{\begin{array}{l} \text{The arc subtended} \\ \text{by } \text{red} \text{ and } \text{blue} \end{array}} \right\} = \frac{2}{5} = \frac{6}{15} \left\{ \begin{array}{l} \text{of the whole} \\ \text{circumference} \end{array} \right.$

The arc subtended by — $\left. \vphantom{\begin{array}{l} \text{The arc subtended} \\ \text{by } \text{yellow} \end{array}} \right\} = \frac{1}{3} = \frac{5}{15} \left\{ \begin{array}{l} \text{of the whole} \\ \text{circumference} \end{array} \right.$

$$\text{Their difference} = \frac{1}{15}$$

\therefore the arc subtended by ----- $= \frac{1}{15}$ difference of the whole circumference.

Hence if straight lines equal to ----- be placed in the circle (prop. IV.1), an equilateral and equiangular quindecagon will be thus inscribed in the circle.

Q. E. D.



Book V

Definitions

V.1

A less magnitude is said to be an aliquot part or sub-multiple of a greater magnitude, when the less measures the greater; that is, when the less is contained a certain number of times exactly in the greater.

V.2

A greater magnitude is said to be a multiple of a less, when the greater is measured by the less; that is, when the greater contains the less a certain number of times exactly.

V.3

Ratio is the relation which one quantity bears to another of the same kind, with respect to magnitude.

V.4

Magnitudes are said to have a ratio to one another, when they are of the same kind; and the one which is not the greater can be multiplied so as to exceed the other.

The other definitions will be given throughout the book where their aid is first required.

Axioms

V.1

Equimultiples or equisubmultiples of the same, or of equal magnitudes, are equal.

If $A = B$, then

twice $A =$ twice B ,

that is, $2A = 2B$;

$3A = 3B$;

$4A = 4B$;

etc. etc.

and $\frac{1}{2}$ of $A = \frac{1}{2}$ of B ;

$\frac{1}{3}$ of $A = \frac{1}{3}$ of B ;

$\frac{1}{4}$ of $A = \frac{1}{4}$ of B ;

etc. etc.

V.2

A multiple of a greater magnitude is greater than the same multiple of a less.

Let $A > B$,

then $2A > 2B$;

$3A > 3B$;

$4A > 4B$;

etc. etc.

V.3

That magnitude, of which a multiple is greater than the same multiple of another, is greater than the other.

Let $2A > 2B$,

then $A > B$;

or, let $3A > 3B$,

then $A > B$;

or, let $mA > mB$,

then $A > B$.



If any number of magnitudes be equimultiples of as many others, each of each: what multiple soever any one of the first is of its part, the same multiple shall of the first magnitudes taken together be of all the others taken together.

Let be the same multiple of ,

that is of ,

that is of .

Then is evident that

} is the same multiple of { }

which that is of ;

because there are as many magnitudes







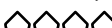

in $\left\{ \begin{array}{c} \text{red squares} \\ \text{yellow diamonds} \\ \text{blue diamonds} \end{array} \right\} = \left\{ \begin{array}{c} \text{red square} \\ \text{yellow diamond} \\ \text{blue diamond} \end{array} \right\}$



as there are in $\text{red squares} = \text{red square}$.

The same demonstration holds in any number of magnitudes, which has here been applied to three.

∴ If any number of magnitudes, etc.

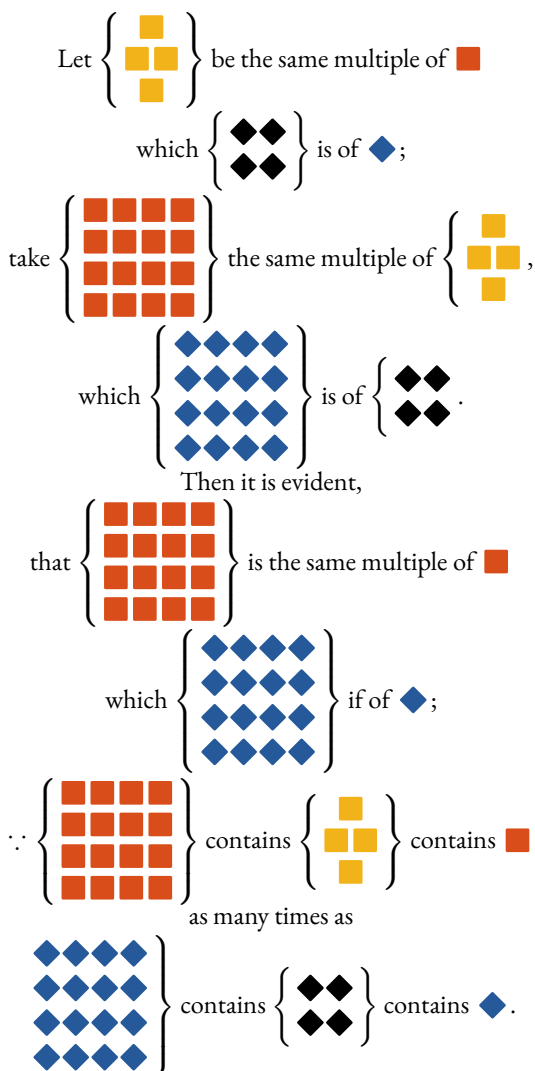
IF the first magnitude be the same multiple of the second that the third of the fourth, and the fifth the same multiple of the second that the sixth is of the fourth, then shall the first, together with the fifth, be the same multiple of the second that the third, together with the sixth, is of the fourth.

Let  , the first, be the same multiple of  , the second, that  , the third, is of  , the fourth; and let  , the fifth, be the same multiple of  , the second, that  , the sixth, is of  , the fourth.

Then it is evident, that $\left\{ \begin{array}{c} \text{yellow circles} \\ \text{blue circles} \end{array} \right\}$, the first and fifth together, is the same multiple of  , the second, that $\left\{ \begin{array}{c} \text{red diamonds} \\ \text{red diamonds} \end{array} \right\}$, the third and sixth together, is of the same multiple of  , the fourth; because there are as many magnitudes in $\left\{ \begin{array}{c} \text{yellow circles} \\ \text{blue circles} \end{array} \right\} = \text{yellow circle}$ as there are in $\left\{ \begin{array}{c} \text{red diamonds} \\ \text{red diamonds} \end{array} \right\} = \text{red diamond}$.

∴ If the first magnitude, etc.





IF the first of four magnitudes be the same multiple of the second that the third is to the fourth, and if any equimultiples whatever of the first and third be taken, those shall be equimultiples; one of the second, and the other of the fourth.

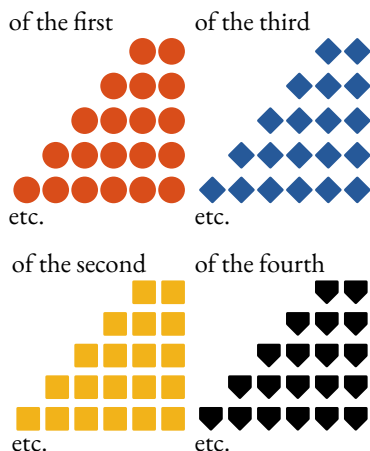


The same reasoning is applicable in all cases.

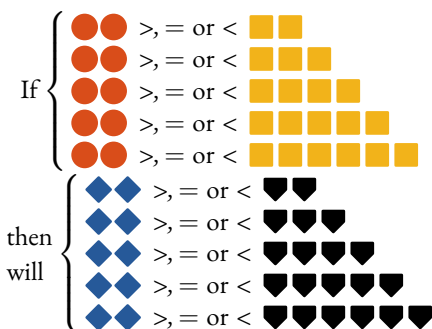
∴ If the first of four, etc.

V.5 Definition V.

Four magnitudes, , , , , are said to be proportionals when every equimultiple of the first and third be taken, and every equimultiple of the second and fourth, as,

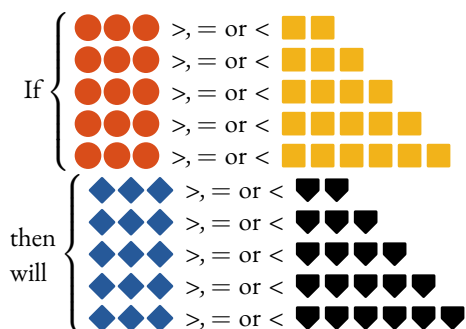


Then taking every pair of equimultiples of the first and third, and every pair of equimultiples of the second and fourth,

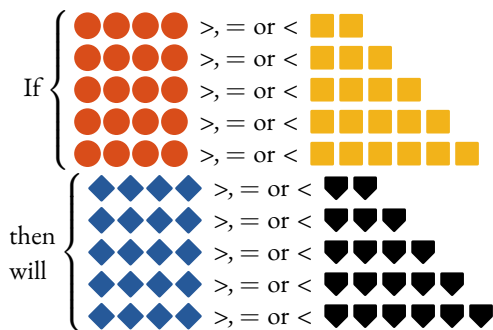


That is, if twice the first be greater, equal, or less than twice the second, twice the third will be greater, equal, or less than twice the fourth; or, if twice the first be greater, equal, or less than three times the second, twice the third

will be greater, equal, or less than three times the fourth, and so on, as above expressed.



In other terms, if three times the first be greater, equal, or less than twice the second, three times the third will be greater, equal, or less than twice the fourth; or, if three times the first be greater, equal, or less than three times the second, then will three times the third be greater, equal, or less than three times the fourth; or if three times the first be greater, equal, or less than four times the second, then will three times the third be greater, equal, or less than four times the fourth, and so on. Again,



And so on, with any other equimultiples of the four magnitudes, taken in the same manner.

Euclid expresses this definition as follows :—

The first of four magnitudes is said to have the same ratio to the second, which the third has to the fourth, when equimultiples whatsoever of the first and third being taken, and any equimultiples whatsoever of the second and fourth; if the multiple of the first be less than that of the second, and the multiple of the third is also less than that of the fourth; or, if the multiple of the first be equal to that of the second, the multiple of the third is also equal to that of the fourth; or, if the multiple of the first be greater than that of the second, the multiple of the third is also greater than that of the fourth.

In future we shall express this definition generally, thus:

$$\begin{aligned} &\text{If } M \text{ } \bullet >, = \text{ or } < m \text{ } \blacksquare, \\ &\text{when } M \text{ } \blacklozenge >, = \text{ or } < m \text{ } \blacktriangledown, \end{aligned}$$

Then we infer that \bullet , the first, has the same ratio to \blacksquare , the second, which \blacklozenge , the third, has to \blacktriangledown the fourth; expressed in the succeeding demonstrations thus:

$$\begin{aligned} &\bullet : \blacksquare :: \blacklozenge : \blacktriangledown; \\ &\text{or thus, } \bullet : \blacksquare = \blacklozenge : \blacktriangledown; \\ &\text{or thus, } \frac{\bullet}{\blacksquare} = \frac{\blacklozenge}{\blacktriangledown}; \\ &\text{and is read,} \\ &\text{"as } \bullet \text{ is to } \blacksquare, \text{ so is } \blacklozenge \text{ to } \blacktriangledown." \\ &\text{And if } \bullet : \blacksquare :: \blacklozenge : \blacktriangledown \text{ we shall infer if} \\ &M \bullet >, = \text{ or } < m \blacksquare, \text{ then will} \\ &M \blacklozenge >, = \text{ or } < m \blacktriangledown. \end{aligned}$$

That is, if the first be to the second, as the third is to the fourth; then if M times the first be greater than, equal to, or less than m times the second, then shall M times third be greater than, equal to, or less than m times the fourth, in which M and m are not to be considered particular multiples, but every pair of multiples whatever; nor

are such marks as , , , etc. to be considered any more than representatives of geometrical magnitudes.

The student should thoroughly understand this definition before proceeding further.

IF the first of four magnitudes have the same ratio to the second, which the third has to the fourth, then any equimultiples whatever of the first and third shall have the same ratio to any equimultiples of the second and fourth; viz., the equimultiple of the first shall have the same ratio to that of the second, which the equimultiple of the third has to that of the fourth.

Let $\text{yellow circle} : \blacksquare :: \text{red diamond} : \text{blue diamond}$, then $3 \text{ yellow circle} : 2 \blacksquare :: 3 \text{ red diamond} : 2 \text{ blue diamond}$, every equimultiple of 3 yellow circle and 3 red diamond are equimultiples of yellow circle and red diamond , and every equimultiple of $2 \blacksquare$ and 2 blue diamond , are equimultiples of \blacksquare and blue diamond (prop. V.3)

That is, M times 3 yellow circle and M times 3 red diamond are equimultiples of yellow circle and red diamond , and m times $2 \blacksquare$ and $m2 \text{ blue diamond}$ are equimultiples of $2 \blacksquare$ and 2 blue diamond ; but $\text{yellow circle} : \blacksquare :: \text{red diamond} : \text{blue diamond}$ (hyp.); \therefore if $M3 \text{ yellow circle} <, =, \text{ or } > m2 \blacksquare$, then $M3 \text{ red diamond} <, =, \text{ or } > m2 \text{ blue diamond}$ (def. V.5) and therefore $3 \text{ yellow circle} : 2 \blacksquare :: 3 \text{ red diamond} : 2 \text{ blue diamond}$ (def. V.5)

The same reasoning holds good if any other equimultiple of the first and third be taken, any other equimultiple of the second and fourth.

\therefore If the first four magnitudes, etc.

I

If one magnitude be the same multiple of another, which a magnitude taken from the first is of a magnitude taken from the other, the remainder shall be the same multiple of the remainder, that the whole is of the whole.

$$\text{Let } \begin{array}{c} \diamond \\ \diamond \diamond \end{array} = M' \begin{array}{c} \blacktriangle \\ \blacksquare \end{array}$$

$$\text{and } \begin{array}{c} \square \\ \square \end{array} = M' \blacksquare,$$

$$\therefore \begin{array}{c} \diamond \\ \diamond \diamond \end{array} - \begin{array}{c} \square \\ \square \end{array} = M' \begin{array}{c} \blacktriangle \\ \blacksquare \end{array} - M' \blacksquare,$$

$$\therefore \begin{array}{c} \diamond \\ \diamond \diamond \end{array} = M' \left(\begin{array}{c} \blacktriangle \\ \blacksquare \end{array} - \blacksquare \right),$$

$$\text{and } \therefore \begin{array}{c} \diamond \\ \diamond \diamond \end{array} = M' \blacktriangle.$$

\therefore If one magnitude, etc.

IF two magnitudes be equimultiples of two others, and if equimultiples of these be taken from the first two, the remainders are either equal to these others, or equimultiples of them.

Let $\begin{array}{c} \diamond \\ \diamond \diamond \\ \diamond \end{array} = M' \blacksquare$; and $\begin{array}{c} \square \\ \square \square \end{array} = M' \blacktriangle$

then $\begin{array}{c} \diamond \\ \diamond \diamond \\ \diamond \end{array} - m' \blacksquare = M' \blacksquare - m' \blacksquare = (M' - m') \blacksquare$

and $\begin{array}{c} \square \\ \square \square \end{array} - m' \blacktriangle = M' \blacktriangle - m' \blacktriangle = (M' - m') \blacktriangle$.

Hence, $(M' - m') \blacksquare$ and $(M' - m') \blacktriangle$ are equimultiples of \blacksquare and \blacktriangle , and equal to \blacksquare and \blacktriangle , when

$$M' - m' = 1.$$

\therefore If two magnitudes be equimultiples, etc.



If the first of the four magnitudes has the same ratio to the second which the third has to the fourth, then if the first be greater than the second, the third is also greater than the fourth; and if equal, equal; if less, less.

Let $\bullet : \blacksquare :: \blacktriangledown : \blacklozenge$; therefore, by the fifth definition, if $\bullet\bullet > \blacksquare\blacksquare$, then will $\blacktriangledown\blacktriangledown > \blacklozenge\blacklozenge$; but if $\bullet > \blacksquare$, then $\bullet\bullet > \blacksquare\blacksquare$ and $\blacktriangledown\blacktriangledown > \blacklozenge\blacklozenge$, and $\therefore \blacktriangledown > \blacklozenge$. Similarly, if $\bullet =$, or $< \blacksquare$, then will $\blacktriangledown =$, or $< \blacklozenge$. \therefore If the first of four, etc.

V.14 Definition XIV

Geometricians make use of the technical term “Invertendo,” by inversion, when there are four proportionals, and it is inferred, that the second is to the first as the fourth to the third.

Let $A : B :: C : D$, then, by “invertendo” it is inferred $B : A :: D : C$



If four magnitudes are proportionals, they are proportionals also when taken inversely.

Let $\heartsuit : \square :: \blacksquare : \blacklozenge$,

then, inversely, $\square : \heartsuit :: \blacklozenge : \blacksquare$.

If $M \heartsuit < m \square$, then $M \blacksquare < m \blacklozenge$

by the fifth definition.

Let $M \heartsuit < m \square$, that is, $m \square > M \heartsuit$,

$\therefore M \blacksquare < m \blacklozenge$, or, $m \blacklozenge > M \blacksquare$;

\therefore if $m \square > M \heartsuit$, then will $m \blacklozenge > M \blacksquare$.

In the same manner it may be shown,

that if $m \square =$ or $< M \heartsuit$,

then will $m \blacklozenge =$, or $< M \blacksquare$;

and therefore, by the fifth definition, we infer



that $\square : \heartsuit :: \blacklozenge : \blacksquare$.



\therefore If four magnitudes, etc.











F the first be the same multiple of the second, or the same part of it, that the third is of the fourth; the first is to the second, as the third is to the fourth.



,


Let , the first, be the same multiple of , the second,



that , the third, is of , the fourth.

Then  :  ::  : 

take M , m , M , m 



because  is the same multiple of 

that  is of  (according to the hypothesis);




and M  if taken the same multiple of 




that M  is of ,





\therefore (according to the third proposition),


M  is the same multiple of 

that M  is of .

Therefore, if M  be of  a greater multiple than m  is,


then M  is a greater multiple of  than m  is;

that is, if M  be greater than m , then M  will be greater than m 

in the same manner it can be shown, if M  be equal


$m \bullet$, then M  will be equal $m \blacktriangle$.

And, generally, if M  $>$, $=$ or $< m \bullet$

than M  will be $>$, $=$ or $< m \blacktriangle$;


\therefore by the fifth definition,

$$\begin{array}{c} \text{four blue squares} \\ \text{four blue squares} \end{array} : \bullet :: \begin{array}{c} \text{four yellow diamonds} \\ \text{four yellow diamonds} \end{array} : \blacktriangle$$


Next, let \bullet be the same part of 

that \blacktriangle is of .

In this case also $\bullet : \begin{array}{c} \text{four blue squares} \\ \text{four blue squares} \end{array} :: \blacktriangle : \begin{array}{c} \text{four yellow diamonds} \\ \text{four yellow diamonds} \end{array}$.

For, because \bullet is the same part of  that \blacktriangle is of



therefore  is the same multiple of \bullet

that  is of \blacktriangle .

Therefore, by the preceding case,

$$\begin{array}{c} \text{four blue squares} \\ \text{four blue squares} \end{array} : \bullet :: \begin{array}{c} \text{four yellow diamonds} \\ \text{four yellow diamonds} \end{array} : \blacktriangle;$$

and $\therefore \bullet : \begin{array}{c} \text{four blue squares} \\ \text{four blue squares} \end{array} :: \blacktriangle : \begin{array}{c} \text{four yellow diamonds} \\ \text{four yellow diamonds} \end{array},$

by proposition B.



\therefore If the first be the same multiple, etc.

I









If the first be to the second as the third to the fourth, and if the first be a multiple, or a part of the second; the third is the same multiple, or the same part of the fourth.

Let  :  ::  : ;

and first, let  be a multiple ;



 shall be the same multiple of .

First Second Third Fourth



Take  = .

Whatever multiple  is of 





take  the same multiple of ,



then, \therefore  :  ::  : 

and of the second and fourth, we have taken equimultiples,

 and  therefore (prop. V.4)

 :  ::  : , but (const.),

 =  \therefore (prop. V.A)  = 

and  is the same multiple of 

that  is of .

Next, let $\blacksquare : \begin{array}{c} \bullet \\ \bullet \bullet \end{array} :: \blacktriangledown : \begin{array}{c} \blacklozenge \blacklozenge \\ \blacklozenge \blacklozenge \end{array},$

and also \blacksquare a part of $\begin{array}{c} \bullet \\ \bullet \bullet \end{array};$

then \blacktriangledown shall be the same part of $\begin{array}{c} \blacklozenge \blacklozenge \\ \blacklozenge \blacklozenge \end{array}.$

Inversely (prop. V.B), $\begin{array}{c} \bullet \\ \bullet \bullet \end{array} : \blacksquare :: \begin{array}{c} \blacklozenge \blacklozenge \\ \blacklozenge \blacklozenge \end{array} : \blacktriangledown,$

but \blacksquare is a part of $\begin{array}{c} \bullet \\ \bullet \bullet \end{array};$

that is, $\begin{array}{c} \bullet \\ \bullet \bullet \end{array}$ is a multiple of \blacksquare ;

\therefore by the preceding case, $\begin{array}{c} \blacklozenge \blacklozenge \\ \blacklozenge \blacklozenge \end{array}$ is the same multiple of \blacktriangledown

that is, \blacktriangledown is the same part of $\begin{array}{c} \blacklozenge \blacklozenge \\ \blacklozenge \blacklozenge \end{array}$

that \blacksquare is of $\begin{array}{c} \bullet \\ \bullet \bullet \end{array}.$

\therefore if the first be to the second, etc.

E

QUAL magnitudes have the same ratio to the same magnitude, and the same has the same ratio to equal magnitudes.

Let $\bullet = \blacklozenge$ and \blacksquare any other magnitude;
then $\bullet : \blacksquare = \blacklozenge : \blacksquare$ and $\blacksquare : \bullet = \blacksquare : \blacklozenge$.

$$\therefore \bullet = \blacklozenge,$$

$$\therefore M \bullet = M \blacklozenge;$$

\therefore if $M \bullet >, =$ or $< m \blacksquare$, then

$$M \blacklozenge >, = \text{ or } < m \blacksquare,$$

and $\therefore \bullet : \blacksquare = \blacklozenge : \blacksquare$ (def. V.5).

From the foregoing reasoning it is evident that,

if $m \blacksquare >, =$ or $< M \bullet$, then





$$m \blacksquare >, = \text{ or } < M \blacklozenge$$

$\therefore \blacksquare : \bullet = \blacksquare : \blacklozenge$ (def. V.5).









\therefore Equal magnitudes, etc.




V.15 Definition VII.

When of the equimultiples of four magnitudes (taken as in the fifth definition), the multiple of the first is greater than that of the second, but multiple of the third is not greater than the multiple of the fourth; then the first is said to have to the second a greater ratio than the third magnitude has to the fourth: and, on the contrary, the third is said to have to the fourth a less ratio than the first has to the second.

If, among the equimultiples of four magnitudes, compared in the fifth definition, we should find  $>$ , but  $=$ or $>$ , or if we should find any particular multiple M' of the first and third, and a particular multiple m' of the second and fourth, such, that M' times the first is $>$ m' times the second, but M' times the third is not $>$ m' times the fourth, i. e. $=$ or $<$ m' times the fourth; then the first is said to have to the second a greater ratio than the third has to the fourth; or the third has to the fourth, under such circumstances, a less ratio than the first has to the second: although several other equimultiples may tend to show that the four magnitudes are proportionals.

This definition will in future be expressed thus :—

If M'  $>$ m' , but M'  $=$ or $<$ m' ,
then  :  $>$  : .

In the above general expression, M' and m' are to be considered particular multiples, not like the multiples M and m introduced in the fifth definition, which are in that definition considered to be every pair of multiples that can be taken. It must also be here observed, that , , , and the like symbols are to be considered merely the representatives of geometrical magnitudes.

In a partial arithmetical way, this may be set forth as follows:

Let us take the four numbers 8, 7, 10, and 9.

First	Second	Third	Fourth
8	7	10	9
16	14	20	18
24	21	30	27
32	28	40	36
40	35	50	45
48	42	60	54
56	49	70	63
64	56	80	72
72	63	90	81
80	70	100	90
88	77	110	99
96	84	120	108
104	91	130	117
112	98	140	126
etc.	etc.	etc.	etc.

Among the above multiples we find $16 > 14$ and $20 > 18$; that is, twice the first is greater than twice the second, and twice the third is greater than twice the fourth; and $16 < 21$ and $20 < 27$; that is, twice the first is less than three times the second, and twice the third is less than three times the fourth; and among the same multiples we can find $72 > 56$ and $90 > 72$; that is, 9 times the first is greater than 8 times the second, and 9 times the third is greater than 8 times the fourth. Many other equimultiples might be selected, which would tend to show that the numbers 8, 7, 10, and 9 were proportionals, but they are not, for we can find multiple of the first $>$ a multiple of the second, but the same multiple of the third that has been taken of the first not $>$ the same multiple of the fourth which has been taken to the second; for instance, 9 times the first is $>$ 10 times the second, but 9 times the third is not $>$ 10 times the fourth, that is $72 > 70$, but $90 \not> 90$, or 8 times the first we find $>$ 9 times the second, but 8 times the third is not greater than 9 times the fourth, that is, $64 > 63$, but

80 not $>$ 81. When any such multiples as these can be found, the first (8) is said to have the second (7) a greater ratio than the third (10) has to the fourth (9), and on the contrary the third (10) is said to have to the fourth (9) a less ratio than the first (8) has to the second (7).



Of unequal magnitudes the greater has a greater ratio to the same than the less has: and the same magnitude has a greater ratio to the less than it has to the greater.

Let \blacktriangle and \blacksquare be two unequal magnitudes,
and \bullet any other.

We shall first prove that \blacktriangle which is the greater of the
two unequal magnitudes, has a greater ratio to \bullet than

\blacksquare , the less, has to \bullet ; that is, $\blacktriangle : \bullet > \blacksquare : \bullet$;

take $M' \blacktriangle$, $m' \bullet$, $M' \blacksquare$, $m' \bullet$;
such, that $M' \blacktriangle$ and $M' \blacksquare$ shall be each $> \bullet$;
also take $m' \bullet$ the least multiple of \bullet ,
which will make $m' \bullet > M' \blacksquare = M' \blacktriangle$;
 $\therefore M' \blacksquare$ is $\nless m' \bullet$,

but $M' \blacktriangle$ is $> m' \bullet$, for,
as $m' \bullet$ is the first multiple which first becomes
 $> M' \blacksquare$, than $(m' - 1) \bullet$ or $m' \bullet - \bullet$ is $\nless M' \blacktriangle$,
and $\bullet \nless M' \blacktriangle$
 $\therefore m' \bullet - \bullet + \bullet$ must be $< M' \blacksquare + M' \blacktriangle$;

that is, $m' \bullet$ must be $< M' \blacktriangle$;

$\therefore M' \blacktriangle$ is $> m' \bullet$; but it has been shown above that
 $M' \blacksquare$ is $\nless m' \bullet$, therefore, by the seventh definition,

\blacktriangle has to \bullet a greater ratio than $\blacksquare : \bullet$.

Next we shall prove that \bullet has a greater ratio to \blacksquare , the

less, than it has to \blacktriangle , the greater;

or, $\bullet : \blacksquare > \bullet : \blacktriangle$.

Take $m' \bullet$, $M' \blacksquare$, $m' \bullet$ and $M' \blacktriangle$,

the same as in the first case, such that $M' \blacktriangle$ and $M' \blacksquare$ will be each $> \bullet$, and $m' \bullet$ the least multiple of \bullet , which first becomes greater than

$$M' \blacksquare = M' \blacktriangle.$$

$$\therefore m' \bullet - \bullet \text{ is } \neq M' \blacksquare,$$

and \bullet is $\neq M' \blacktriangle$; consequently

$$m' \bullet - \bullet + \bullet \text{ is } < M' \blacksquare + M' \blacktriangle;$$

$\therefore m' \bullet$ is $< M' \blacktriangle$, and \therefore by the seventh definition,

\bullet has to \blacktriangle a greater ratio than \bullet has to \blacksquare .

\therefore Of unequal magnitudes, etc.

The contrivance employed in this proposition for finding among the multiples taken, as in the fifth definition, a multiple of the first greater than the multiple of the second, but the same multiple of the third which has been taken of the first, not greater than the same multiple of the fourth which has been taken of the second, may be illustrated numerically as follows :—

The number 9 has a greater ratio to 7 than 8 has to 7: that is, $9 : 7 > 8 : 7$; or $8 + 1 : 7 > 8 : 7$.

The multiple of 1, which first becomes greater than 7, is 8 times, therefore, we may multiply the first and third by 8, 9, 10, or any other greater number; in this case, let us multiply the first and third by 8, and we have $64 + 8$ and 64: again, the first multiple of 7 which becomes greater than 64 is 10 times; then, by multiplying the second and fourth by 10, we shall have 70 and 70; then, arranging these multiples, we have—

8 times the first	10 times the second	8 times the third	10 times the fourth
$64 + 8$	70	64	70

Consequently $64 + 8$, or 72, is greater than 70, but 64 is not greater than 70, \therefore by the seventh definition 9 has a greater ratio to 7 than 8 has to 7.

The above is merely illustrative of the foregoing demonstration, for this property could be shown of these or other numbers very readily in the following manner; because, if an antecedent contains its consequent a greater number of times than another antecedent contains its consequent, or when a fraction is formed of an antecedent for the numerator, and its consequent for the denominator be greater than another fraction which is formed of another antecedent for the numerator and its consequent for the denominator, the ratio of the first antecedent to its consequent is greater than the ratio of the last antecedent to its consequent.

Thus, the number 9 has a greater ratio to 7, than 8 has to 7, for $\frac{9}{7}$ is greater than $\frac{8}{7}$.

Again, 17 : 19 is a greater ratio than 13 : 15, because $\frac{17}{19} = \frac{17 \times 15}{19 \times 15} = \frac{255}{185}$, and $\frac{13}{15} = \frac{13 \times 19}{15 \times 19} = \frac{247}{185}$, hence it is evident that $\frac{255}{185}$ is greater than $\frac{247}{185}$, $\therefore \frac{17}{19}$ is greater than $\frac{13}{15}$, and, according to what has been above shown, 17 has to 19 a greater ratio than 13 has to 15.

So that the general terms upon which a greater, equal, or less ratio exists are as follows :—

If $\frac{A}{B}$ be greater than $\frac{C}{D}$, A is said to have to B a greater ratio than C has to D ; if $\frac{A}{B}$ be equal to $\frac{C}{D}$, then A has to B the same ratio which C has to D ; and if $\frac{A}{B}$ be less to $\frac{C}{D}$, A is said to have to B a less ratio than C has to D .

The student should understand all up to this proposition perfectly before proceeding further, in order fully to comprehend the following propositions of this book. We therefore strongly recommend the learner to commence again, and read up to this slowly, and carefully reason at each step, as he proceeds, particularly guarding against the mischievous system of depending wholly on the memory. By following these instructions, he will find that the parts which usually present considerable difficulties will present no difficulties whatever, in prosecuting the study of this important book.



AGNITUDES which have the same ratio to the same magnitude are equal to one another; and those to which the same magnitude has the same ratio are equal to one another.

Let $\blacklozenge : \blacksquare :: \bullet : \blacksquare$, then $\blacklozenge = \bullet$.

For, if not, let $\blacklozenge > \bullet$, then will

$\blacklozenge : \blacksquare > \bullet : \blacksquare$ (prop. V.8), which is absurd according to the hypothesis.

$\therefore \blacklozenge$ is $\neq \bullet$.

In the same manner it may be shown, that

\bullet is $\neq \blacklozenge$,

$\therefore \blacklozenge = \bullet$.

Again, let $\blacksquare : \blacklozenge :: \blacksquare : \bullet$,

then will $\blacklozenge = \bullet$.

For (invert.) $\blacklozenge : \blacksquare :: \bullet : \blacksquare$,

therefore, by the first case, $\blacklozenge = \bullet$.

\therefore Magnitudes which have the same ratio, etc.

This may be shown otherwise, as follows :—

Let $A : B = A : C$, then $B = C$, for, as the fraction $\frac{A}{B}$ = the fraction $\frac{A}{C}$, and the numerator of one equal to the numerator of the other, therefore, denominators of these fractions are equal, that is $B = C$.

Again, if $B : A = C : A$, $B = C$. For, as $\frac{B}{A} = \frac{C}{A}$, B must = C .



THAT magnitude which has a greater ratio than another has unto the same magnitude, is the greater of the two; and that magnitude to which the same has a greater ratio than it has unto another magnitude, is the less of the two.

Let $\blacktriangleleft : \blacksquare > \bullet : \blacksquare$, then $\blacktriangleleft > \bullet$.

For if not, let $\blacktriangleleft =$ or $< \bullet$;

then, $\blacktriangleleft : \blacksquare = \bullet : \blacksquare$ (prop. V.7) or

$\blacktriangleleft : \blacksquare < \bullet : \blacksquare$ (prop. V.8) and (invert.), which is absurd according to the hypothesis.

$\therefore \blacktriangleleft$ is \neq or $< \bullet$, and

$\therefore \blacktriangleleft$ must be $> \bullet$.

Again, let $\blacksquare : \bullet > \blacksquare : \blacktriangleleft$,

then, $\bullet < \blacktriangleleft$.

For if not, \bullet must be $>$ or $= \blacktriangleleft$,

then $\blacksquare : \bullet < \blacksquare : \blacktriangleleft$ (prop. V.8) and (invert.);

or $\blacksquare : \bullet = \blacksquare : \blacktriangleleft$ (prop. V.7), which is absurd (hyp.);

$\therefore \bullet$ is \neq or $= \blacktriangleleft$,

and $\therefore \bullet$ must be $< \blacktriangleleft$.

\therefore That magnitude which has, etc.



RATIOS that are the same to the same ratio, are the same to each other.

Let $\blacklozenge : \blacksquare = \bullet : \blacktriangledown$ and $\bullet : \blacktriangledown = \blacktriangle : \bullet$,
 then will $\blacklozenge : \blacksquare = \blacktriangle : \bullet$.
 For if $M\blacklozenge >, =$ or $< m\blacksquare$,
 then $M\bullet >, =$ or $< m\blacktriangledown$,
 and if $M\bullet >, =$ or $< m\blacktriangledown$,
 then $M\blacktriangle >, =$ or $< m\bullet$ (def. V.5);
 \therefore if $M\blacklozenge >, =$ or $< m\blacksquare$, $M\blacktriangle >, =$ or $< m\bullet$
 and \therefore (def. V.5) $\blacklozenge : \blacksquare = \blacktriangle : \bullet$.
 \therefore Ratios that are the same etc.



If any number of magnitudes be proportionals, as one of the antecedents is to its consequent, so shall all the antecedents taken together be to all the consequents.

Let

$$\blacksquare : \bullet = \square : \diamond = \blacklozenge : \blacktriangledown = \bullet : \blacktriangledown = \blacktriangle : \bullet;$$

$$\text{then will } \blacksquare : \bullet = \blacksquare + \square + \blacklozenge + \bullet + \blacktriangle :$$

$$\bullet + \diamond + \blacktriangledown + \blacktriangledown + \bullet.$$

$$\text{For if } M\blacksquare > m\bullet, \text{ then } M\square > m\diamond,$$

$$\text{and } M\blacklozenge > m\blacktriangledown, M\bullet > m\blacktriangledown,$$

$$\text{also } M\blacktriangle > m\bullet \text{ (def. V.5)}$$

Therefore, if $M\blacksquare > m\bullet$, then will

$$M\blacksquare + M\square + M\blacklozenge + M\bullet + M\blacktriangle, \text{ or}$$

$$M(\blacksquare + \square + \blacklozenge + \bullet + \blacktriangle) \text{ be greater than}$$

$$m\bullet + m\diamond + m\blacktriangledown + m\blacktriangledown + m\bullet, \text{ or}$$

$$m(\bullet + \diamond + \blacktriangledown + \blacktriangledown + \bullet).$$

In the same way it may be shown, if M times one of the antecedents be equal to or less than m times one of the consequents, M times all the antecedents taken together, will be equal to or less than m times all the consequents taken together. Therefore, by the fifth definition, as one of the antecedents is to its consequent, so are all the antecedents taken together to all the consequents taken together.

\therefore If any number of magnitudes, etc.

If the first has to the second the same ratio which the third has to the fourth, but the third to the fourth a greater ratio than the fifth has to the sixth; the first shall also have to the second a greater ratio than the fifth to the sixth.

Let $\heartsuit : \spadesuit = \blacksquare : \blacklozenge$, but $\blacksquare : \blacklozenge > \blacktriangle : \bullet$,
 then $\heartsuit : \spadesuit > \blacktriangle : \bullet$

For, $\because \blacksquare : \blacklozenge > \blacktriangle : \bullet$, there are some multiples
 (M' and m') of \blacksquare and \blacktriangle , and of \blacklozenge and \bullet ,
 such that $M' \blacksquare > m' \blacklozenge$,

but $M' \blacktriangle \not> m' \bullet$, by the seventh definition.

Let these multiples be taken, and take the same multiples
 of \heartsuit and \spadesuit .

\therefore (def. V.5) if $M' \heartsuit >, =$, or $< m' \spadesuit$;

then will $M' \blacksquare >, =$, or $< m' \blacklozenge$,

but $M' \blacksquare > m' \blacklozenge$ (construction);

$\therefore M' \heartsuit > m' \spadesuit$,

but $M' \blacktriangle$ is $\not> m' \bullet$ (construction);

and therefore by the seventh definition,

$\heartsuit : \spadesuit > \blacktriangle : \bullet$

\therefore If the first has to the second, etc.

If the first has the same ratio to the second which the third has to the fourth; then, if the first be greater than the third, the second shall be greater than the fourth; and if equal, equal; and if less, less.

Let $\heartsuit : \square :: \blacksquare : \blacklozenge$, and first suppose

$\heartsuit > \blacksquare$, then will $\square > \blacklozenge$.

For $\heartsuit : \square > \blacksquare : \square$ (prop. V.8), and by the hypothesis $\heartsuit : \square = \blacksquare : \blacklozenge$;

$\therefore \blacksquare : \blacklozenge > \blacksquare : \square$ (prop. V.13),

$\therefore \blacklozenge < \square$ (prop. V.10), or $\square > \blacklozenge$.

Secondly, let $\heartsuit = \blacksquare$, then will $\square = \blacklozenge$.

For $\heartsuit : \square = \blacksquare : \square$ (prop. V.7),

and $\heartsuit : \square = \blacksquare : \blacklozenge$ (hyp.);

$\therefore \blacksquare : \square = \blacksquare : \blacklozenge$ (prop. V.11),

and $\therefore \square = \blacklozenge$ (prop. V.9).

Thirdly, if $\heartsuit < \blacksquare$, then will $\square < \blacklozenge$;

$\therefore \blacksquare > \heartsuit$ and $\blacksquare : \blacklozenge = \heartsuit : \square$;



$\therefore \blacklozenge > \square$, by the first case,





that is, $\square < \blacklozenge$.

\therefore If the first has the same ratio, etc.



AGNITUDES *have the same ratio to one another which their equimultiples have.*

Let  and  be two magnitudes;

then,  :  :: M'  : M' .





For  :  =  : 

=  : 

=  : 

\therefore  :  :: 4  : 4 . (prop. V.12).

And as the same reasoning is generally applicable, we have

 :  :: M'  : M' .

\therefore Magnitudes have the same ratio, etc.

V.8 Definition XIII

The technical term *permutando*, or *alternando*, by permutation or alternately, is used when there are four proportionals, and it is inferred that the first has the same ratio to the third which the second has to the fourth; or that the first is to the third as the second to the fourth: as is shown in the following proposition :—

Let $\text{yellow circle} : \text{black diamond} :: \text{red heart} : \text{blue square}$,
 by “*permutando*” or “*alternando*” it is inferred
 $\text{yellow circle} : \text{red heart} :: \text{black diamond} : \text{blue square}$.

It may be necessary here to remark that the magnitudes yellow circle , black diamond , red heart , blue square , must be homogeneous, that is, of the same nature or similitude of kind; we must therefore, in such cases, compare lines with lines, surfaces with surfaces, solids with solids, etc. Hence the student will readily perceive that a line and a surface, a surface and a solid, or other heterogenous magnitudes, can never stand in the relation of antecedent and consequent.



f four magnitudes of the same kind be proportionals, they are also proportionals when taken alternately.

Let $\heartsuit : \square :: \blacksquare : \blacklozenge$, then $\heartsuit : \blacksquare :: \square : \blacklozenge$.

For $M\heartsuit : M\square :: \heartsuit : \square$ (prop. V.15),
and $M\heartsuit : M\square :: \blacksquare : \blacklozenge$ (hyp.) and (prop. V.11);

also $m\blacksquare : m\blacklozenge :: \blacksquare : \blacklozenge$ (prop. V.15);

$\therefore M\heartsuit : M\square :: m\blacksquare : m\blacklozenge$ (prop. V.14),

and \therefore if $M\heartsuit >, =$ or $< m\blacksquare$,

then will $M\square >, =$ or $< m\blacklozenge$ (prop. V.14);

therefore, by the fifth definition,

$$\heartsuit : \blacksquare :: \square : \blacklozenge$$

\therefore If four magnitudes of the same kind, etc.

V.16 Definition XVI

Dividendo, by division, when there are four proportionals, and it is inferred, that the excess of the first above the second is to the second, as the excess of the third above the fourth, is to the fourth.

Let $A : B :: C : D$;

by “dividendo” it is inferred

$$A - B : B :: C - D : D.$$

According to the above, A is supposed to be greater than B , and C greater than D ; if this be not the case, but to have B greater than A , and D greater than C , B and D can be made to stand as antecedents, and A and C as consequents, by “inversion”

$$B : A :: D : C;$$

then, by “dividendo,” we infer

$$B - A : A :: D - C : C$$



If magnitudes, taken jointly, be proportionals, they shall also be proportionals when taken separately: that is, if two magnitudes together have to one of them the same ratio which two others have to one of these, the remaining one of the first two shall have to the other the same ratio which the remaining one of the last two has to the other of these.

Let $\heartsuit + \square : \square :: \blacksquare + \blacklozenge : \blacklozenge$,

then will $\heartsuit : \square :: \blacksquare : \blacklozenge$.

Take $\heartsuit > m\square$ to each add $M\square$,

then we have $M\heartsuit + M\square > m\square + M\square$,

or $M(\heartsuit + \square) > (m + M)\square$:

but $\therefore \heartsuit + \square : \square :: \blacksquare + \blacklozenge : \blacklozenge$ (hyp.),

and $M(\heartsuit + \square) > (m + M)\square$;

$\therefore M(\blacksquare + \blacklozenge) > (m + M)\blacklozenge$ (def. V.5);

$\therefore M\blacksquare + M\blacklozenge > m\blacklozenge + M\blacklozenge$;

$\therefore M\blacksquare > m\blacklozenge$, by taking $M\blacklozenge$ from both sides:

that is, when $M\heartsuit > m\square$, then $M\blacksquare > m\blacklozenge$.

In the same manner it may be proved, that if

$M\heartsuit =$ or $< m\square$, then will $M\blacksquare =$ or $< m\blacklozenge$;

and $\therefore \heartsuit : \square :: \blacksquare : \blacklozenge$ (def. V.5)

\therefore If magnitudes taken jointly, etc.

V.15 Definition XV

The term componendo, by composition, is used when there are four proportionals; and it is inferred that the first together with the second is to the second as the third together with the fourth is to fourth.

Let $A : B :: C : D$;

then, by term “componendo,” it is inferred that

$$A + B : B :: C + D : D$$

By “inversion” B and D may become the first and the third, and A and C the second and fourth, as

$$B : A :: D : C,$$

then, by “componendo,” we infer that

$$B + A : A :: D + C : C.$$

IF magnitudes, taken separately, be proportionals, they shall also be proportionals taken jointly: that is, if the first be to the second as the third is to the fourth, the first and second together shall be to the second as the third and fourth together is to the fourth.

Let $\heartsuit : \square :: \blacksquare : \spadesuit$,
 then $\heartsuit + \square : \square :: \blacksquare + \spadesuit : \spadesuit$;
 for if not, let $\heartsuit + \square : \square :: \blacksquare + \bullet : \bullet$,
 supposing $\bullet \neq \spadesuit$;
 $\therefore \heartsuit : \square :: \blacksquare : \bullet$ (prop. V.17)
 but $\heartsuit : \square :: \blacksquare : \spadesuit$ (hyp.);
 $\therefore \blacksquare : \bullet :: \blacksquare : \spadesuit$ (prop. V.11);
 $\therefore \bullet = \spadesuit$ (prop. V.9),
 which is contrary to the supposition;
 $\therefore \bullet$ is not unequal to \spadesuit ;
 that is $\bullet = \spadesuit$;
 $\therefore \heartsuit + \square : \square :: \blacksquare + \spadesuit : \spadesuit$.
 \therefore If magnitudes, taken separately, etc.

IF a whole magnitude be to a whole, as a magnitude taken from the first, is to a magnitude taken from the other; the remainder shall be to the remainder, as the whole to the whole.

Let $\heartsuit + \square : \blacksquare + \diamond :: \heartsuit : \blacksquare$,
 then will $\square : \diamond :: \heartsuit + \square : \blacksquare + \diamond$.
 For $\heartsuit + \square : \heartsuit :: \blacksquare + \diamond : \blacksquare$ (alter.),
 $\therefore \square : \heartsuit :: \diamond : \blacksquare$ (divid.),
 again $\square : \diamond :: \heartsuit : \blacksquare$ (alter.),
 but $\heartsuit + \square : \blacksquare + \diamond :: \heartsuit : \blacksquare$ (hyp.);
 therefore $\square : \diamond :: \heartsuit + \square : \blacksquare + \diamond$ (prop. V.11).
 \therefore If a whole magnitude be to a whole, etc.

V.17 Definition XVII

The term “convertendo,” by conversion, is made use of by geometricians, when there are four proportionals, and it is inferred, that the first is to its excess above the second, as the third is to its excess above the fourth. See the following proposition :—

I

If four magnitudes be proportionals, they are also proportionals by conversion: that is, the first is to its excess above the second, as the third is to its excess above the fourth.

Let $\bullet \circ : \circ :: \blacksquare \blacklozenge : \blacklozenge$,
 then shall $\bullet \circ : \bullet :: \blacksquare \blacklozenge : \blacksquare$.
 $\therefore \bullet \circ : \circ :: \blacksquare \blacklozenge : \blacklozenge$;
 $\therefore \bullet : \circ :: \blacksquare : \blacklozenge$ (divid.),
 $\therefore \circ : \bullet :: \blacklozenge : \blacksquare$ (inver.),
 $\therefore \bullet \circ : \bullet :: \blacksquare \blacklozenge : \blacksquare$ (compo.).
 \therefore If four magnitudes, etc.

V.18 Definition XVIII

“Ex æquali” (sc. distantia), or ex æquo, from equality of distance: when there is any number of magnitudes more than two, and as many others, such that they are proportionals when taken two and two of each rank, and it is inferred that the first is to the last of the first rank of magnitudes, as the first is to the last of the others: “of this there are two following kinds, which arise from the different order in which the magnitudes are taken, two and two.”

V.19 Definition XIX

“Ex æquali,” from equality. This term is used simply by itself, when the first magnitude is to the second of the first rank, as the first to the second of the other rank; and as the second to the third of the first rank, so is the second to the third of the other; and so in order: and the inference is as mentioned in the preceding definition; whence this is called ordinate proposition. It is demonstrated in (prop. V.22).











Thus, if there be two ranks of magnitudes,
 A, B, C, D, E, F , the first rank, and L, M, N, O, P, Q , the
 second, such that $A : B :: L : M, B : C :: M : N,$
 $C : D :: N : O, D : E :: O : P, E : F :: P : Q;$
 we infer by the term “ex æquali” that $A : F :: L : Q$

V.20 Definition XX





“Ex æquali in proportione perturbatâ seu inordinatâ,” from equality in perturbate, or disorderly proportion. This term is used when the first magnitude is to the second of the first rank as the last but one is to the last of the second rank; and as the second is to the third of the first rank, so is the last but two to the last but one of the second rank; and as the third is to the fourth of the first rank, so is the third from the last to the last but two of the second rank; and so on in a cross order: and the inference is in the 18th definition. It is demonstrated in (prop. V.23).

Thus, if there be two ranks of magnitudes,
 A, B, C, D, E, F , the first rank, and L, M, N, O, P, Q , the
 second, such that $A : B :: P : Q, B : C :: O : P,$
 $C : D :: N : O, D : E :: M : N, E : F :: L : M;$
 the term “ex æquali in proportione perturbatâ seu
 inordinatâ” infers that $A : F :: L : Q$

I*F there be three magnitudes, and other three, which taken two and two, have the same ratio; then, if the first be greater than the third, the fourth shall be greater than the sixth; and if equal, equal; and if less, less.*

Let , , , the first three magnitudes,
and , , , be the other three,
such that  :  ::  : , and

$$\text{red square} : \text{yellow square} :: \text{red diamond} : \text{yellow circle}.$$

Then, if  $>$, $=$, or $<$ ,
then will  $>$, $=$, or $<$ .



From the hypothesis, by alternando, we have

$$\text{blue diamond} : \text{blue diamond} :: \text{red square} : \text{red diamond},$$

$$\text{and } \text{red square} : \text{red diamond} :: \text{yellow square} : \text{yellow circle}$$

$$\therefore \text{blue diamond} : \text{blue diamond} :: \text{yellow square} : \text{yellow circle} \text{ (prop. V.11);}$$

$$\therefore \text{if } \text{blue diamond} >, =, \text{ or } < \text{ yellow square},$$

then will  $>$, $=$, or $<$  (prop. V.14).

\therefore If there be three magnitudes, etc.

IF there be three magnitudes, and other three which have the same ratio, taken two and two, but in a cross order; then if the first magnitude be greater than the third, the fourth shall be greater than the sixth; and if equal, equal, and if less, less.

Let $\color{brown}{\blacklozenge}$, $\color{red}{\blacklozenge}$, $\color{blue}{\blacksquare}$, be the first three magnitudes,

and $\color{blue}{\blacklozenge}$, $\color{red}{\blacklozenge}$, $\color{yellow}{\bullet}$, the other three,

such that $\color{brown}{\blacklozenge} : \color{red}{\blacklozenge} :: \color{red}{\blacklozenge} : \color{yellow}{\bullet}$,

and $\color{red}{\blacklozenge} : \color{blue}{\blacksquare} :: \color{blue}{\blacklozenge} : \color{red}{\blacklozenge}$.

Then if $\color{brown}{\blacklozenge} >, =, \text{ or } < \color{blue}{\blacksquare}$,

then will $\color{blue}{\blacklozenge} >, =, \text{ or } < \color{yellow}{\bullet}$.

First, let $\color{brown}{\blacklozenge}$ be $> \color{blue}{\blacksquare}$:

then, because $\color{red}{\blacklozenge}$ is any other magnitude,

$\color{brown}{\blacklozenge} : \color{red}{\blacklozenge} > \color{blue}{\blacksquare} : \color{red}{\blacklozenge}$ (prop. V.8);

but $\color{red}{\blacklozenge} : \color{yellow}{\bullet} :: \color{brown}{\blacklozenge} : \color{red}{\blacklozenge}$ (hyp.);

$\therefore \color{red}{\blacklozenge} : \color{yellow}{\bullet} > \color{blue}{\blacksquare} : \color{red}{\blacklozenge}$ (prop. V.13);

and $\color{red}{\blacklozenge} : \color{blue}{\blacksquare} :: \color{blue}{\blacklozenge} : \color{red}{\blacklozenge}$ (hyp.);

$\therefore \color{blue}{\blacksquare} : \color{red}{\blacklozenge} :: \color{red}{\blacklozenge} : \color{blue}{\blacklozenge}$ (inv.),

and it was shown that $\color{red}{\blacklozenge} : \color{yellow}{\bullet} > \color{blue}{\blacksquare} : \color{red}{\blacklozenge}$,

$\therefore \color{red}{\blacklozenge} : \color{yellow}{\bullet} > \color{red}{\blacklozenge} : \color{blue}{\blacklozenge}$ (prop. V.13);

$\therefore \color{yellow}{\bullet} < \color{blue}{\blacklozenge}$,

that is $\color{blue}{\blacklozenge} > \color{yellow}{\bullet}$.

Secondly, let $\color{brown}{\blacklozenge} = \color{blue}{\blacksquare}$; then shall $\color{blue}{\blacklozenge} = \color{yellow}{\bullet}$.

For $\color{brown}{\blacklozenge} = \color{blue}{\blacksquare}$,

$\color{brown}{\blacklozenge} : \color{red}{\blacklozenge} = \color{blue}{\blacksquare} : \color{red}{\blacklozenge}$ (prop. V.7);

but $\color{brown}{\blacklozenge} : \color{red}{\blacklozenge} = \color{red}{\blacklozenge} : \color{yellow}{\bullet}$ (hyp.),

and $\color{blue}{\blacksquare} : \color{red}{\blacklozenge} = \color{red}{\blacklozenge} : \color{blue}{\blacklozenge}$ (hyp. and inv.),

$\therefore \color{red}{\blacklozenge} : \color{yellow}{\bullet} = \color{red}{\blacklozenge} : \color{blue}{\blacklozenge}$ (prop. V.11),

$\therefore \color{blue}{\blacklozenge} = \color{yellow}{\bullet}$ (prop. V.9).

Next, let $\color{brown}{\blacklozenge}$ be $< \color{blue}{\blacksquare}$, then $\color{blue}{\blacklozenge}$ shall be $< \color{yellow}{\bullet}$;

for $\color{blue}{\blacksquare} > \color{brown}{\blacklozenge}$,

and it has been shown that $\color{blue}{\blacksquare} : \color{red}{\blacklozenge} = \color{red}{\blacklozenge} : \color{blue}{\blacklozenge}$,

and $\color{red}{\blacklozenge} : \color{brown}{\blacklozenge} = \color{yellow}{\bullet} : \color{red}{\blacklozenge}$;

\therefore by the first case $\color{yellow}{\bullet}$ is $> \color{blue}{\blacklozenge}$,



















that is, $\color{blue}{\blacklozenge} < \color{yellow}{\bullet}$.

\therefore If there be three, etc.























If there be any number of magnitudes, and as many others, which, taken two and two in order, have the same ratio; the first shall have to the last of the first magnitudes the same ratio which the first of the others has to the last of the same.





N.B.— This is usually cited by the words “ex æquali,” or “ex æquo.”

First, let there be magnitudes , , ,
and as many others , , ,
such that
 :  ::  : ,
and  :  ::  : ,
then shall  :  ::  : .

Let these magnitudes, as well as any equimultiples whatever of the antecedents and consequents of the ratios, stand as follows :—

, , , , , ,
and
 M , m , N , M , m , N ,
∴  :  ::  : ,
∴ M  : m  :: M  : m  (prop. V.4).

For the same reason



m  : N  :: m  : N ;



and because there are three magnitudes

M , m , N ,





and other three, M , m , N ,

which, taken two and two, have the same ratio;

∴ if M  $>$, $=$ or $<$ N 

then will M  $>$, $=$ or $<$ N , by (prop. V.20),





and ∴  :  ::  :  (def. V.5).

Next, let there be four magnitudes, , , , ,

and other four, , , , ,







which, taken two and two, have the same ratio,

that is to say,  :  ::  : ,

 :  ::  : ,

and $\blacksquare : \blacklozenge :: \blacklozenge : \blacktriangle$,
 then shall $\blacktriangleleft : \blacklozenge :: \triangleleft : \blacktriangle$;
 for, $\because \blacktriangleleft, \blacklozenge, \blacksquare$, are three magnitudes,
 and $\triangleleft, \bullet, \blacklozenge$, other three,
 which, taken two and two, have the same ratio;
 therefore, by the foregoing case $\blacktriangleleft : \blacksquare :: \triangleleft : \blacklozenge$,
 but $\blacksquare : \blacklozenge :: \blacklozenge : \blacktriangle$;
 therefore again, by the first case, $\blacktriangleleft : \blacklozenge :: \triangleleft : \blacktriangle$;
 and so on, whatever the number of magnitudes be.
 \therefore If there be any number, etc.

IF there be any number of magnitudes, and as many others, which, taken two and two in a cross order, have the same ratio; the first shall have to the last of the first magnitudes the same ratio which the first of the others has to the last of the same.
N.B.— This is usually cited by the words “ex æquali in proportionē perturbatā;” or “ex æquo perturbato.”





First, let there be three magnitudes , , ,
 and other three, , , ,
 which, taken two and two in a cross order, have the same
 ratio;

that is,  :  ::  : ,
 and  :  ::  : ,
 then shall  :  ::  : .

Let these magnitudes and their respective equimultiples be arranged as follows :—

, , , , , ,
 M , M , m , M , m , m ,
 then  :  :: M  : M  (prop. V.15);

and for the same reason

 :  :: m  : m .

but  :  ::  :  (hyp.),

$\therefore M$  : M  ::  :  (prop. V.11);

and \therefore  :  ::  :  (hyp.),

$\therefore M$  : m  :: M  : m  (prop. V.4);



then, because there are three magnitudes,

M , M , m ,

and other three M , m , m ,

which, taken two and two in a cross order, have the same
 ratio;

therefore, if M , $>$, $=$, or $<$ m ,

then will M , $>$, $=$, or $<$ m  (prop. V.21),

and \therefore  :  ::  :  (def. V.5).

Next, let there be four magnitudes,

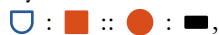
, , , ,

and other four,



which, when taken two and two in a cross order, have the same ratio;

namely, $\text{yellow diamond} : \text{blue diamond} :: \text{black square} : \text{black triangle}$,



and $\text{red square} : \text{yellow diamond} :: \text{blue diamond} : \text{red circle}$,

then shall $\text{red square} : \text{yellow diamond} :: \text{blue diamond} : \text{red circle}$.

For, \therefore yellow diamond , blue diamond , red square are three magnitudes,

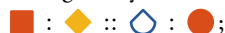
and red circle , black square , black triangle , other three,

which, taken two and two in a cross order have the same ratio,

therefore, by the first case, $\text{yellow diamond} : \text{red square} :: \text{red circle} : \text{black triangle}$,

but $\text{red square} : \text{yellow diamond} :: \text{blue diamond} : \text{red circle}$,

therefore again, by the first case,



and so on, whatever be the number of such magnitudes.

\therefore If there be any number, etc.



If the first has to the second the same ratio which the third has to the fourth, and the fifth to the second the same which the sixth has to the fourth, the first and fifth together shall have to the second the same ratio which the third and sixth together have to the fourth.

First Second Third Fourth



Fifth

Sixth



Let $\blacktriangle : \square :: \blacksquare : \blacklozenge$,

and $\triangle : \square :: \bullet : \blacklozenge$,

then $\blacktriangle + \triangle : \square :: \blacksquare + \bullet : \blacklozenge$.

For $\triangle : \square :: \bullet : \blacklozenge$ (hyp.),

and $\square : \blacktriangle :: \blacklozenge : \blacksquare$ (hyp.) and (invert.),

$\therefore \triangle : \blacktriangle :: \bullet : \blacksquare$ (prop. V.22);

and, because these magnitudes are proportionals, they
are proportionals when taken jointly,

$\therefore \blacktriangle + \triangle : \triangle :: \bullet + \blacksquare : \blacksquare$ (prop. V.18),

but $\triangle : \square :: \bullet : \blacklozenge$ (hyp.),

$\therefore \blacktriangle + \triangle : \square :: \bullet + \blacksquare : \blacklozenge$ (prop. V.22)

\therefore If the first, etc.

IF four magnitudes of the same kind are proportionals, the greatest and least of them together are greater than the other two together.

Let four magnitudes, $\heartsuit + \square$, $\blacksquare + \diamond$, \square , and \diamond ,
of the same kind, be proportionals, that is to say,

$$\heartsuit + \square : \blacksquare + \diamond :: \square : \diamond,$$

and let $\heartsuit + \square$ be the greatest of the four, and
consequently by (prop. V.A and prop. V.14), \diamond is the
least;

then will $\heartsuit + \square + \diamond$ be $> \blacksquare + \diamond + \square$;

$$\therefore \heartsuit + \square : \blacksquare + \diamond :: \square : \diamond,$$

$$\therefore \heartsuit : \blacksquare :: \heartsuit + \square : \blacksquare + \diamond \text{ (prop. V.19),}$$

but $\heartsuit + \square > \blacksquare + \diamond$ (hyp.),

$$\therefore \heartsuit > \blacksquare \text{ (prop. V.A);}$$

to each of these add $\square + \diamond$,

$$\therefore \heartsuit + \square + \diamond > \blacksquare + \square + \diamond.$$

\therefore If four magnitudes, etc.

V.10 Definition X

When three magnitudes are proportionals, the first is said to have to the third the duplicate ratio of that which it has to the second.

For example, if A, B, C , be continued proportionals, that is, $A : B :: B : C$, A is said to have to C the duplicate ratio of $A : B$;

$$\text{or } \frac{A}{C} = \text{the square of } \frac{A}{B}.$$

This property will be more readily seen of the quantities

$$ar^2, ar, a, \text{ for } ar^2 : ar :: ar : a;$$

$$\text{and } \frac{ar^2}{a} = r^2 = \text{the square of } \frac{ar^2}{ar} = r,$$

$$\text{or of } a, ar, ar^2;$$

$$\text{for } \frac{a}{ar^2} = \frac{1}{r^2} = \text{the square of } \frac{a}{ar} = \frac{1}{r}.$$

V.II Definition XI

When four magnitudes are continual proportionals, the first is said to have to the fourth the triplicate ratio of that which is has to the second; and so on, quadruplicate, etc. increasing the denomination still by unity, in any number of proportionals.

For example, let A, B, C, D , be four continued proportionals, that is, $A : B :: B : C :: C : D$; A is said to have to D , the triplicate ratio of A to B ;

$$\text{or } \frac{A}{D} = \text{the cube of } \frac{A}{B}.$$

This definition will be better understood, and applied to a greater number of magnitudes than four that are continued proportionals, as follows :—

Let ar^3, ar^2, ar, a , be four magnitudes in continued proportion, that is, $ar^3 : ar^2 :: ar^2 : ar :: ar : a$,

$$\text{then } \frac{ar^3}{a} = r^3 = \text{the cube of } \frac{ar^3}{ar^2} = r.$$

Or, let $ar^5, ar^4, ar^3, ar^2, ar, a$, be six magnitudes in proportion, that is

$$ar^5 : ar^4 :: ar^4 : ar^3 :: ar^3 : ar^2 :: ar^2 : ar :: ar : a,$$

then the ratio $\frac{ar^5}{a} = r^5 = \text{the fifth power of } \frac{ar^5}{ar^4} = r$

Or, let a, ar, ar^2, ar^3, ar^4 , be five magnitudes in continued proportion; then $\frac{a}{ar^4} = \frac{1}{r^4} =$
the fourth power of $\frac{a}{ar} = \frac{1}{r}$.

V.A Definition A

To know a compound ratio :—

When there are any number of magnitudes of the same kind, the first is said to have to the last of them the ratio compounded of the ratio which the first has to the second, and of the ratio which the second has to the third, and of the ratio which the third has to the fourth; and so on, unto the last magnitude.

For example, if A, B, C, D , be four magnitudes of the same kind, the first A is said to have to the last D the ratio compounded of the ratio of A to B , and of the ratio of B to C , and of the ratio of C to D ; or, the ratio of A to D is said to be compounded of the ratios of A to B , B to C , and C to D .

And if A has to B the same ratio which E has to F , and B to C the same ratio that G has to H , and C to D the same that K has to L ; then by this definition, A is said to have to D the ratio compounded of ratios which are the same with the ratios of E to F , G to H , and K to L . And the same thing is to be saying, A has to D the ratio compounded of the ratios of E to F , G to H , and K to L .

In like manner, the same things being supposed; if M has to N the same ratio which A has to D , then for shortness sake, M is said to have to N the ratio compounded of the ratios E to F , G to H , and K to L .

This definition may be better understood from an arithmetical or algebraical illustration; for, in fact, a ratio compounded of several other ratios, is nothing more than a ratio which has for its antecedent the continued product of all antecedents of the ratios compounded, and for its consequent the continued product of all the consequents of the ratios compounded.

Thus, the ratio compounded of the ratios of

$2 : 3, 4 : 7, 6 : 11, 2 : 5,$

$A B C D$ $E F G H K L$ $M N$

is the ratio of $2 \times 4 \times 6 \times 2 : 3 \times 7 \times 11 \times 5$,
or the ratio of 96 : 1155, or 32 : 385.

And of the magnitudes A, B, C, D, E, F , of the same kind, $A : F$ is the ratio compounded of the ratios of

$$A : B, B : C, C : D, D : E, E : F;$$

for $A \times B \times C \times D \times E : B \times C \times D \times E \times F$,

$$\text{or } \frac{A \times B \times C \times D \times E}{B \times C \times D \times E \times F} = \frac{A}{F}, \text{ or the ratio of } A : F.$$



ATIOS which are compounded of the same ratios are same to one another.

Let $A : B :: F : G$,
 $B : C :: G : H$,
 $C : D :: H : K$,
 and $D : E :: K : L$,

A	B	C	D	E
F	G	H	K	L

Then the ratio which is compounded by the ratios of $A : B$, $B : C$, $C : D$, $D : E$, or the ratio of $A : E$, is the same as the ratio compounded of the ratios $F : G$, $G : H$, $H : K$, $K : L$, or the ratio of $F : L$.

$$\begin{aligned} \text{For } \frac{A}{B} &= \frac{F}{G}, \\ \frac{B}{C} &= \frac{G}{H}, \\ \frac{C}{D} &= \frac{H}{K}, \\ \text{and } \frac{D}{E} &= \frac{K}{L}; \\ \therefore \frac{A \times B \times C \times D}{B \times C \times D \times E} &= \frac{F \times G \times H \times K}{G \times H \times K \times L}, \\ \text{and } \therefore \frac{A}{E} &= \frac{F}{L}, \end{aligned}$$

or the ratio of $A : E$ is the same as the ratio $F : L$.

The same may be demonstrated of any number of ratios so circumstanced.

Next, let $A : B :: K : L$,
 $B : C :: H : K$,
 $C : D :: G : H$,
 $D : E :: F : G$,

Then the ratio which is compounded of the ratios of $A : B$, $B : C$, $C : D$, $D : E$, or the ratio of $A : E$, is the same as the ratio compounded of the ratios of $K : L$, $H : K$, $G : H$, $F : G$, or the ratio of $F : L$.

$$\text{For } \frac{A}{B} = \frac{K}{L},$$

$$\frac{B}{C} = \frac{H}{G},$$

$$\frac{C}{D} = \frac{G}{H},$$

$$\text{and } \frac{D}{E} = \frac{F}{G};$$

$$\therefore \frac{A \times B \times C \times D}{B \times C \times D \times E} = \frac{K \times H \times G \times F}{L \times K \times H \times G},$$

$$\text{and } \therefore \frac{A}{E} = \frac{F}{L},$$

or the ratio of $A : E$ is the same as the ratio $F : L$.

\therefore Ratios which are compounded, etc.



If several ratios be the same to several ratios, each to each, the ratio which is compounded of ratios which are the same to the first ratios, each to each, shall be the same to the ratio compounded of ratios which are the same to the other ratios, each to each.

<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>	<i>F</i>	<i>G</i>	<i>H</i>	<i>P</i>	<i>Q</i>	<i>R</i>	<i>S</i>	<i>T</i>
<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>	<i>g</i>	<i>h</i>	<i>V</i>	<i>W</i>	<i>X</i>	<i>Y</i>	<i>Z</i>

If $A : B :: a : b$ and $A : B :: P : Q$ and $a : b :: V : W$

$C : D :: c : d$ $C : D :: Q : R$ $c : d :: W : X$

$E : F :: e : f$ $E : F :: R : S$ $e : f :: X : Y$

and $G : H :: g : h$ $G : H :: S : T$ $f : h :: Y : Z$

then $P : T = V : Z$.

For $\frac{P}{Q} = \frac{A}{B} = \frac{a}{b} = \frac{V}{W}$

$\frac{Q}{R} = \frac{C}{D} = \frac{c}{d} = \frac{W}{X}$

$\frac{R}{S} = \frac{E}{F} = \frac{e}{f} = \frac{X}{Y}$

$\frac{S}{T} = \frac{G}{H} = \frac{g}{h} = \frac{Y}{Z}$

and $\therefore \frac{P \times Q \times R \times S}{Q \times R \times S \times T} = \frac{V \times W \times X \times Y}{W \times X \times Y \times Z}$,

and $\therefore \frac{P}{T} = \frac{V}{Z}$,

or $P : T = V : Z$.

\therefore If several ratios, etc.

IF a ratio which is compounded of several ratios be the same to a ratio which is compounded of several other ratios; and if one of the first ratios, or the ratio which is compounded of several of them, be the same to one of the last ratios, or to the ratio which is compounded of several of them; then the remaining ratio of the first, or, if there be more than one, the ratio compounded of the remaining ratios, shall be the same to the remaining ratios, shall be the same to the remaining ratio of the last, or, if there be more than one, to the ratio, compounded of these remaining ratios.

$A B C D E F G H$ $P Q R S T X$

Let $A : B, B : C, C : D, D : E, E : F, F : G, G : H$, be the first ratios, and $P : Q, Q : R, R : S, S : T, T : X$, the other ratios; also, let $A : H$, which is compounded of the first ratios, be the same as the ratio of $P : X$, which is the ratio compounded of the other ratios; and, let the ratio of $A : E$, which is compounded of the ratios of $A : B, B : C, C : D, D : E$, be the same as the ratio of $P : R$, which is compounded of the ratios $P : Q, Q : R$.

Then the ratio which is compounded of the remaining first ratios, that is, the ratio compounded of the ratios $E : F, F : G, G : H$, that is, the ratio of $E : H$, shall be the same as the ratio of $R : X$, which is compounded of the ratios of $R : S, S : T, T : X$, the remaining other ratios.

$$\begin{aligned}
 &\text{Because } \frac{A \times B \times C \times D \times E \times F \times G}{B \times C \times D \times E \times F \times G \times H} = \frac{P \times Q \times R \times S \times T}{Q \times R \times S \times T \times X}, \\
 &\text{or } \frac{A \times B \times C \times D}{B \times C \times D \times E} \times \frac{E \times F \times G}{F \times G \times H} = \frac{P \times Q}{Q \times R} \times \frac{R \times S \times T}{S \times T \times X}, \\
 &\text{and } \frac{A \times B \times C \times D}{B \times C \times D \times E} = \frac{P \times Q}{Q \times R} \\
 &\therefore \frac{E \times F \times G}{F \times G \times H} = \frac{R \times S \times T}{S \times T \times X},
 \end{aligned}$$

$$\begin{aligned} &\therefore \frac{E}{H} = \frac{R}{X}, \\ &\therefore E : H = R : X. \\ &\therefore \text{If a ratio which, etc.} \end{aligned}$$

IF there be any number of ratios, and any number of other ratios, such that the ratio which is compounded of ratios, which are the same to the first ratios, each to each, is the same to the ratio which is compounded of ratios, which are the same, each to each, to the last ratios—and if one of the first ratios, or the ratio which is compounded of ratios, which are the same to several of the first ratios, each to each, be the same to one of the last ratios, or to the ratio which is compounded of ratios, which are the same, each to each, to several of the last ratios—then the remaining ratio of the first; or, if there be more than one, the ratio which is compounded of ratios, which are the same, each to each, to the remaining ratios of the first, shall be the same to the remaining ratio of the last; or, if there be more than one, to the ratio which is compounded of ratios, which are the same, each to each, to these remaining ratios.

												<i>b</i>	<i>k</i>	<i>m</i>	<i>n</i>	<i>s</i>								
<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>	<i>F</i>	<i>G</i>	<i>H</i>	<i>K</i>	<i>L</i>	<i>M</i>	<i>N</i>	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>	<i>g</i>						
<i>O</i>	<i>P</i>	<i>Q</i>	<i>R</i>	<i>S</i>	<i>T</i>	<i>V</i>	<i>W</i>	<i>X</i>	<i>Y</i>										<i>h</i>	<i>k</i>	<i>l</i>	<i>m</i>	<i>n</i>	<i>p</i>
				<i>a</i>	<i>b</i>	<i>k</i>	<i>m</i>					<i>e</i>	<i>f</i>	<i>g</i>										

Let *A* : *B*, *C* : *D*, *E* : *F*, *G* : *H*, *K* : *L*, *M* : *N*, be the first ratios, and *O* : *P*, *Q* : *R*, *S* : *T*, *V* : *W*, *X* : *Y*, the other ratios;

and let *A* : *B* = *a* : *b*,

C : *D* = *b* : *c*,

E : *F* = *c* : *f*,

G : *H* = *d* : *e*,

K : *L* = *e* : *f*,

M : *N* = *f* : *g*.

Then, by the definition of a compound ratio, the ratio of *a* : *g* is compounded of the ratios of *a* : *b*, *b* : *c*, *c* : *d*, *d* : *e*, *e* : *f*, *f* : *g*, which are the same as the ratio of *A* : *B*, *C* : *D*, *E* : *F*, *G* : *H*, *K* : *L*, *M* : *N*, each to each.

Also, $O : P = b : k$,

$Q : R = k : l$,

$S : T = l : m$,

$V : W = m : n$,

$X : Y = n : p$,

Then will the ratio of $b : p$ be the ratio compounded of the ratios of $b : k, k : l, l : m, m : n, n : p$, which are the same as the ratios of $O : P, Q : R, S : T, V : W, X : Y$, each to each.

\therefore by the hypothesis $a : g = b : p$.

Also, let the ratio which is compounded of the ratios of $A : B, C : D$, two of the first ratios (or the ratios of $a : c$ for $A : B = a : b$, and $C : D = b : c$), be the same as the ratio of $a : d$, which is compounded of the ratios of $a : b, b : c, c : d$, which are the same as the ratios of $O : P, Q : R, S : T$, three of the other ratios.

And let the ratios of $b : s$, which is compounded of the ratios of $b : k, k : m, m : n, n : s$, which are the same as the remaining first ratios, namely, $E : F, G : H, K : L, M : N$; also, let the ratio of $e : g$, be that which is compounded of the ratios $e : f, f : g$, which are the same, each to each, to the remaining other ratios, namely $V : W, X : Y$. Then the ratios of $b : s$ shall be the same as the ratio of $e : g$; or $b : s = e : g$.

$$\begin{aligned}
 & \text{For} \\
 & \frac{A \times C \times E \times G \times K \times M}{B \times D \times F \times H \times L \times N} = \frac{a \times b \times c \times d \times e \times f}{b \times c \times d \times e \times f \times g}, \\
 & \text{and} \quad \frac{O \times Q \times S \times V \times X}{P \times R \times T \times W \times Y} = \frac{b \times k \times l \times m \times n}{k \times l \times m \times n \times p}, \\
 & \quad \text{by the composition of the ratios;} \\
 & \therefore \frac{a \times b \times c \times d \times e \times f}{b \times c \times d \times e \times f \times g} = \frac{b \times k \times l \times m \times n}{k \times l \times m \times n \times p} \\
 & \quad \text{(hyp.),} \\
 & \text{or} \quad \frac{a \times b}{b \times c} \times \frac{c \times d \times e \times f}{d \times e \times f \times g} = \frac{b \times k \times l}{k \times l \times m} \times \frac{m \times n}{n \times p},
 \end{aligned}$$

$$\text{but } \frac{a \times b}{b \times c} = \frac{\textcolor{red}{A} \times \textcolor{red}{C}}{\textcolor{red}{B} \times \textcolor{red}{D}} = \frac{\textcolor{orange}{O} \times \textcolor{orange}{Q} \times \textcolor{orange}{S}}{\textcolor{brown}{P} \times \textcolor{brown}{R} \times \textcolor{brown}{T}} = \frac{a \times b \times c}{b \times c \times d} =$$

$$\frac{b \times k \times l}{k \times l \times m};$$

$$\therefore \frac{\textcolor{blue}{c} \times \textcolor{blue}{d} \times \textcolor{blue}{e} \times \textcolor{blue}{f}}{\textcolor{blue}{d} \times \textcolor{blue}{e} \times \textcolor{blue}{f} \times \textcolor{blue}{g}} = \frac{m \times n}{n \times p}.$$

$$\text{And } \frac{\textcolor{blue}{c} \times \textcolor{blue}{d} \times \textcolor{blue}{e} \times \textcolor{blue}{f}}{\textcolor{blue}{d} \times \textcolor{blue}{e} \times \textcolor{blue}{f} \times \textcolor{blue}{g}} = \frac{b \times k \times l \times m \times n}{k \times l \times m \times n \times p} \text{ (hyp.),}$$

$$\text{and } \frac{m \times n}{n \times p} = \frac{e \times f}{f \times g} \text{ (hyp.),}$$

$$\therefore \frac{b \times k \times l \times m \times n}{k \times l \times m \times n \times p} = \frac{ef}{fg},$$

$$\therefore \frac{b}{s} = \frac{e}{g},$$

$$\therefore b : s = e : g.$$

\therefore If there be any number, etc.

Book VI

Definitions

VI.1

Rectilinear figures are said to be similar, when they have their several angles equal, each to each, and the sides about the equal angles proportional.

VI.2

Two sides of one figure are said to be reciprocally proportional to two sides of another figure when one of the sides of the first is to the second, as the remaining side of the second is to the remaining side of the first.

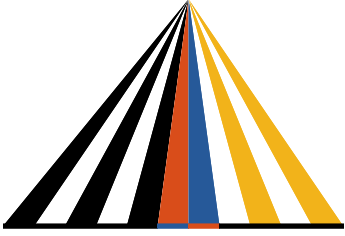
VI.3

A straight line is said to be cut in extreme and mean ratio, when the whole is to the greater segment, as the greater segment is to the less.





VI.4




The altitude of any figure is the straight line drawn from its vertex perpendicular to its base, or the base produced.












TRIANGLES and parallelograms having the same altitude are to one another as their bases.





Let the triangles  and  have a common vertex, and their bases  and  in the same straight line.

Produce  both ways, take successively on  produced lines equal to it; and on  produced lines successively equal to it; and draw lines from the common vertex to their extremities.

The triangles  thus formed are all equal to one another, since their bases are equal. (prop. I.38)

\therefore  and its base are respectively equimultiples of  and the base .

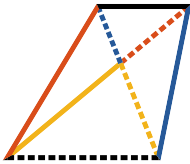
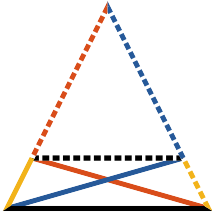
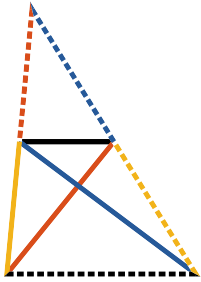
In like manner  and its base are respectively equimultiples of  and the base .



\therefore if m or 6 times  $>$, $=$ or $<$ n or 5 times  then m or 6 times  $>$, $=$ or $<$ n or 5 times , m and n stand for every multiple taken as in the fifth definition of the Fifth Book. Although we have only shown that this property exists when m equal 6, and n equal 5, yet it is evident that the property holds good for every multiple value that may be given to m , and to n .





Parallelograms having the same altitude are the doubles of the triangles, on their bases, and are proportional to them (Part I), and hence their doubles, the parallelograms, are as their bases (prop. V.15).

Q. E. D.



IF a straight line  be drawn parallel to any side  of a triangle, it shall cut the other sides, or those sides produced, into proportional segments

And if any straight line  divide the sides of a triangle, or those sides produced, into proportional segments, it is parallel to the remaining side .

Part I.

Let  \parallel , then shall

$$\text{yellow} : \text{red} :: \text{yellow} : \text{blue}.$$

Draw  and ,

and  =  (prop. I.37);

$$\therefore \text{yellow} : \text{red} :: \text{yellow} : \text{blue} \quad (\text{prop. V.7});$$

but  :  ::  :  (prop. VI.1),









$$\therefore \text{yellow} : \text{red} :: \text{yellow} : \text{blue} \quad (\text{prop. V.II}).$$

Part II.





Let  :  ::  : .



then  || .


Let the same construction remain,

\therefore  :  ::  :  } (prop. VI.1);
and  :  ::  :  }

but  :  ::  :  (hyp.)

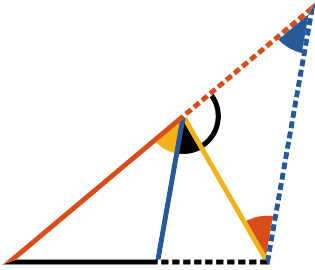
\therefore  :  ::  :  (prop. V.11)

\therefore  =  (prop. V.9);

but they are on the same base , and at the same side of it, and

\therefore  ||  (prop. I.39).

Q. E. D.









RIGHT line (—) bisecting the angle of a triangle, divides the opposite side into segments (—, —) proportional to the conterminous sides (—, —).

And if a straight line (—) drawn from any angle of a triangle divide the opposite side (—) into segments (—, —) proportional to the conterminous sides (—, —), it bisects the angle.

Part I.

Draw — || —, to meet —;

then,  =  (prop. I.29).

\therefore  = ; but  = , \therefore  = ,

\therefore — = — (prop. I.6);

and \therefore — || —,

— : — :: — : — (prop. VI.2);

but — = —;



\therefore — : — :: — : — (prop. V.7).

Part II.

Let the same construction remain,

and  :  ::  : 

(prop. VI.2);

but  :  ::  :  (hyp.)





\therefore  :  ::  :  (prop. V.11).

and \therefore  =  (prop. V.9),

and \therefore  =  (prop. I.5);

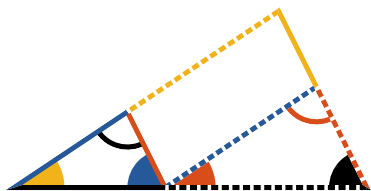
but since  || ;  = ,



and  =  (prop. I.29);







\therefore  = , and  = ,








and \therefore  bisects  .



Q. E. D.





I^N equiangular triangles ( and ) the sides about the equal angles are proportional, and the sides which are opposite to the equal angles are homologous.

Let the equiangular triangles be so placed that two sides —, ---- opposite to equal angles  and  may be conterminous, and in the same straight line; and that the triangles lying at the same side of that straight line; and that the triangles lying at the same side of that straight line, may have the equal angles not conterminous, i. e.  opposite to , and  to .

Draw ---- and —.
Then, \therefore  = ,  \parallel  (prop. I.28);
and for a like reason  \parallel ,
 \therefore  is a parallelogram.

But — : ---- ::  : 
(prop. VI.2);

and since  =  (prop. I.34),

— : ---- ::  : ;



and by alternation

— :  :: ---- :  (prop. V.16).

In like manner it may be shown, that

 :  :: — : ----;

and by alternation, that

 : — ::  : ----;

but it has been already proved that

— :  :: ---- : 

and therefore, ex æquali,

 :  ::  :  (prop. V.22),

therefore the sides about the equal angles are proportional, and those which are opposite to the equal angles are homologous.

Q. E. D.

I *F two triangles have their sides proportional*
($\text{---} : \text{---} :: \text{---} : \text{---}$)
and ($\text{---} : \text{---} :: \text{---} : \text{---}$)
they are equiangular, and the equal
angles are subtended by the homologous sides.

From the extremities of --- , draw --- and

--- , making
 $\triangle = \triangle$, $\triangle = \triangle$ (prop. I.23);

and consequently $\triangle = \triangle$ (prop. I.32),

and since the triangles are equiangular,

$\text{---} : \text{---} :: \text{---} : \text{---}$ (prop. VI.4);

but $\text{---} : \text{---} :: \text{---} : \text{---}$ (hyp.);

$\therefore \text{---} : \text{---} :: \text{---} : \text{---}$, and

consequently $\text{---} = \text{---}$ (prop. V.9). In like

manner it may be shown that

$\text{---} = \text{---}$.

Therefore, the two triangles having a common base

--- , and their sides equal, have also equal angles

opposite to equal sides, i. e.

$\triangle = \triangle$ and $\triangle = \triangle$ (prop. I.8).

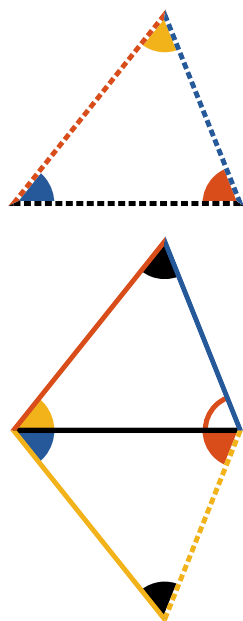
but $\triangle = \triangle$ (const.) and $\therefore \triangle = \triangle$;

for the same reason $\triangle = \triangle$,

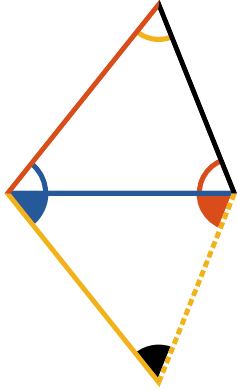
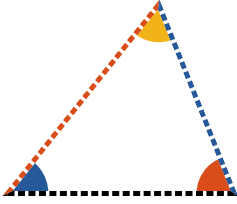
and consequently $\triangle = \triangle$ (prop. I.32);





and therefore the triangles are equiangular, and it is

evident that the homologous sides subtended by the
 equal angles.







Q. E. D.







I F two triangles ( and ) have one angle () of the one, equal to one angle () of the other, and the sides about the equal angles proportional, the triangles shall be equiangular, and have those angles equal which the homologous sides subtend.

From the extremities of , one of the sides of

, about ,

draw  and ,





making  = ,

and  = ;

then  =  (prop. I.32),



and two triangles being equiangular,

 :  ::  :  (prop. VI.4);

but  :  ::  :  (hyp.)

\therefore  :  ::  :  (prop. V.11),

and consequently  =  (prop. V.9);

\therefore  =  in every respect (prop. I.4).

But  =  (const.),

and \therefore  = ;











and since also  = ,

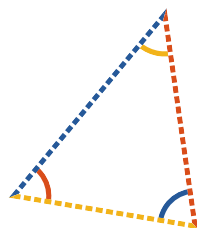
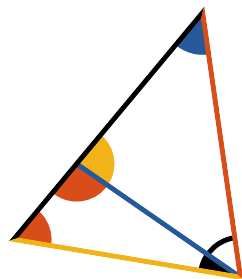
 =  (prop. I.32);








and \therefore  and  are equiangular, with their equal angles opposite to homologous sides.

Q. E. D.



IF two triangles ( and ) have one angle in each equal ( equal to ) , the sides about two other angles ( :  ::  : ), and each of the remaining angles ( and ) either less or not less than a right angle, the triangles are equiangular, and those angles are equal about which the sides are proportional.



First let it be assumed that the angles  and  are each less than a right angle: then if it be supposed that  and  contained by the proportional sides, are not equal, let  be greater, and make  = .

$$\therefore \text{blue angle} = \text{yellow angle} \text{ (hyp.) and } \text{black angle} = \text{blue angle} \text{ (const.)}$$

$$\therefore \text{yellow angle} = \text{red angle} \text{ (prop. I.32);}$$


$$\therefore \text{red side} : \text{blue side} :: \text{dashed red side} : \text{dashed yellow side} \text{ (prop. VI.4),}$$


$$\text{but } \text{red side} : \text{yellow side} :: \text{dashed red side} : \text{dashed yellow side} \text{ (hyp.)}$$


$$\therefore \text{red side} : \text{blue side} :: \text{red side} : \text{yellow side};$$




$$\therefore \text{blue side} = \text{yellow side} \text{ (prop. V.9),}$$



$$\text{and } \therefore \text{red angle} = \text{yellow angle} \text{ (prop. I.5).}$$



But  is less than a right angle (hyp.)



\therefore  is less than a right angle;

and \therefore  must be greater than a right angle (prop. I.13),

but it has been proven =  and therefore less than a right angle, which is absurd. \therefore  and  are not unequal;



\therefore they are equal, and since  =  (hyp.)



\therefore  =  (prop. I.32), and therefore the triangles are equiangular.

But if  and  be assumed to be each not less than a right angle, it may be proved as before, that the triangles are equiangular, and have the sides about equal the angles proportional (prop. VI.4).

Q. E. D.

I

In a right angled triangle (, if a perpendicular () be drawn from the right angle to the opposite side, the triangles



(, ) on each side of it are similar to the whole triangle and to each other.






$$\therefore \text{  } = \text{  } \text{ (ax. I.11),}$$

and  common to  and ;



$$\text{  } = \text{  } \text{ (prop. I.32);}$$

\therefore  and  are equiangular; and consequently have their sides about the equal angles proportional (prop. VI.4), and are therefore similar (def. VI.1).

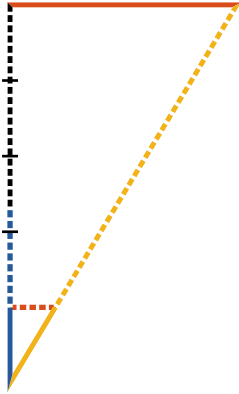
In like manner it may be proved that  is similar to

; but  has been shown to be similar to



\therefore  and  are similar to the whole and to each other.

Q. E. D.



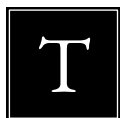
FROM a given straight line (—) to cut off any required part.

From either extremity of the given line draw — making any angle with —; and produce — till the whole produced line — contains — as often as — contains the required part.

Draw —, and draw — || —. — is the required part of —.

For since — || —
 — : — :: — : — (prop. VI.2),
 and by composition (prop. V.18);
 — : — :: — : —;
 but — contains — as often as — contains the required part (const.);
 ∴ — is the required part.

Q. E. D.



o divide a given straight line (— — —) similarly to a given divided line (— — —).

From either extremity of the given line — — — draw

— — — making any angle;

take — — —, — — — and — — — equal to — — —, — — — and — — —

respectively (prop. I.2);

draw — — —, and draw — — — and — — — \parallel to it.

Since $\left\{ \begin{array}{c} \text{— — —} \\ \text{— — —} \end{array} \right\}$ are \parallel ,

— — — : — — — $::$ — — — : — — — (prop. VI.2),

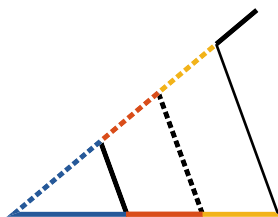
or — — — : — — — $::$ — — — : — — — (const.),

and — — — : — — — $::$ — — — : — — — (prop. VI.2),

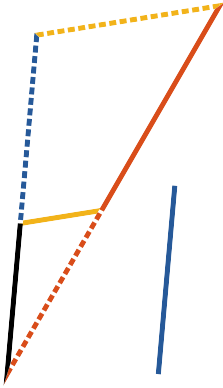
— — — : — — — $::$ — — — : — — — (const.),

and \therefore the given line — — — is divided similarly to

— — —.



Q. E. D.



To find a third proportional to two given straight lines (— and —).

At either extremity of the given line — draw

— making an angle;

take — = —, and draw —;

make — = —,

and draw — || —; (prop. I.31)

— is the third proportional to — and —.

For since — || —,

\therefore — : — :: — : — (prop. VI.2);





but — = — = — (const.);

\therefore — : — :: — : — (prop. V.7).

Q. E. D.




To find a fourth proportional to three given lines $\left\{ \begin{array}{c} \text{blue dashed} \\ \text{red dashed} \\ \text{yellow dashed} \end{array} \right\}$.



Draw  and  and  and  making any angle;


take  = ,

and  = ,

also  = ,

draw ,

and  \parallel  (prop. I.31);

 is the fourth proportional.

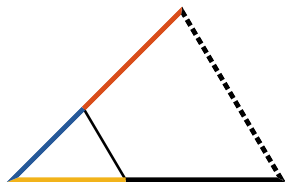
On account of the parallels,

 :  ::  :  (prop. VI.2);

but $\left\{ \begin{array}{c} \text{blue dashed} \\ \text{red dashed} \\ \text{yellow dashed} \end{array} \right\} = \left\{ \begin{array}{c} \text{blue solid} \\ \text{red solid} \\ \text{yellow solid} \end{array} \right\}$ (const.);

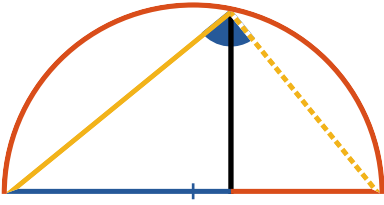
\therefore  :  ::  :  (prop. V.7).









Q. E. D.

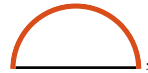





To find a mean proportional between two given straight lines {   }.










Draw any straight line  ,
make  =  and  = ;
bisect  ; and from the point of bisection as a
centre, and half line as a radius, describe a semicircle





draw  \perp :





 is the mean proportional required.

Draw  and .

Since  is a right angle (prop. III.31),
and  is \perp from it upon the opposite side,
 \therefore  is a mean proportional between  and
 (prop. VI.8),
and \therefore between  and  (const.).







Q. E. D.

EQUAL parallelograms  and , which have one angle in each equal, have the sides about the equal angles reciprocally proportional

( :  ::  : )

And parallelograms which have one angle in each equal, and the sides about them reciprocally proportional, are equal.



Let  and ; and  and , be so placed that  and  may be continued right lines. It is evident that they may assume this position. (prop. I.13 to I.15)

Complete .

Since  = ;

\therefore  :  ::  :  (prop. V.7)

\therefore  :  ::  :  (prop. VI.1)

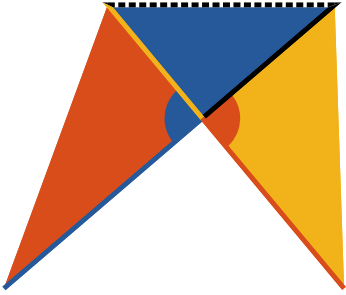
The same construction remaining:







 :  :: $\left\{ \begin{array}{l} \text{ :  (prop. VI.1)} \\ \text{ :  (hyp.)} \\ \text{ :  (prop. VI.1)} \end{array} \right.$

\therefore  :  ::  :  (prop. V.11)

and \therefore  =  (prop. V.9).







Q. E. D.



EQUAL triangles, which have one angle in each equal ( = ), have the sides about the equal angles reciprocally proportional
 ( :  ::  : )

And two triangles which have an angle of the one equal to an angle of the other, and the sides about the equal angles reciprocally proportional, are equal.

I.

Let the triangles be so placed that the equal angles  and  may be vertically opposite, that is to say, so that  and  may be in the same straight line. Whence also  and  must be in the same straight line (prop. I.14).

Draw , then

$$\text{yellow line} : \text{black line} :: \text{red triangle} : \text{blue triangle} \quad (\text{prop. VI.1})$$

$$:: \text{yellow triangle} : \text{blue triangle} \quad (\text{prop. V.7})$$

$$:: \text{red line} : \text{yellow line} \quad (\text{prop. VI.1})$$

$$\therefore \text{blue line} : \text{black line} :: \text{red line} : \text{yellow line} \quad (\text{prop. V.11}).$$

II.



Let the same construction remain, and

 :  ::  :  (prop. VI.1)

and  :  ::  :  (prop. VI.1)

but  :  ::  : , (hyp.)

∴  :  ::  :  (prop. V.11);

∴  =  (prop. V.9).

Q. E. D.



IF four straight lines be proportional (— : — :: — : —) the rectangle (— × —) contained by the extremes, is equal to the rectangle (— × —) contained by the means.

And if the rectangle contained by the extremes be equal to the rectangle contained by the means, the four straight lines are proportional.

Part I.

From the extremities of — and — draw — and — \perp to them and = — and — respectively:

complete the parallelograms — and —.

and since,

$$\begin{aligned} & \text{—} : \text{—} :: \text{—} : \text{—} \quad (\text{hyp.}) \\ \therefore & \text{—} : \text{—} :: \text{—} : \text{—} \quad (\text{const.}) \\ \therefore & \text{—} = \text{—} \quad (\text{prop. VI.14}), \end{aligned}$$

that is, the rectangle contained by the extremes, equal to the rectangle contained by the means.

Part II.

Let the same construction remain;

$$\therefore \text{dotted line} = \text{solid line}, \text{red square} = \text{yellow square}$$

and $\text{red line} = \text{dotted line}$.

$$\therefore \text{yellow line} : \text{blue line} :: \text{red line} : \text{solid line} \text{ (prop. VI.14)}$$

But $\text{red line} = \text{dotted line}$,

and $\text{solid line} = \text{dotted line}$ (const.)

$$\therefore \text{yellow line} : \text{blue line} :: \text{dotted line} : \text{dotted line} \text{ (prop. V.7).}$$

Q. E. D.



IF three straight lines be proportional
 ($\text{red} : \text{blue} :: \text{blue} : \text{black}$)
 the rectangle under the extremes is equal to
 the square of the mean.

And if the rectangle under the extremes be equal to the
 square of the mean, the three straight lines are proportional.

Part I.

Assume $\text{yellow} = \text{blue}$,

and since $\text{red} : \text{blue} :: \text{blue} : \text{black}$,

then $\text{red} : \text{blue} :: \text{yellow} : \text{black}$,

$$\therefore \text{red} \times \text{black} = \text{blue} \times \text{yellow}$$

(prop. VI.16).

But $\text{yellow} = \text{blue}$,

$$\therefore \text{blue} \times \text{yellow} = \text{blue} \times \text{blue} \text{ or } = \text{blue}^2;$$

therefore, if the three straight lines are proportional, the
 rectangle contained be the extremes is equal to the square
 of the mean.

Part II.

Assume $\text{yellow} = \text{blue}$,

then $\text{red} \times \text{black} = \text{yellow} \times \text{blue}$,

$$\therefore \text{red} : \text{blue} :: \text{yellow} : \text{black}$$

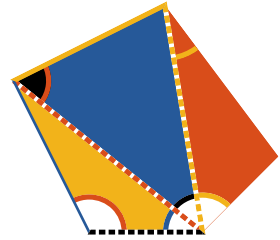
(prop. VI.16),

and $\text{red} : \text{blue} :: \text{blue} : \text{black}$.

Q. E. D.



ON a given straight line (—) to construct a rectilinear figure similar to a given one () and similarly placed.

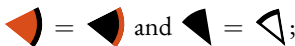


Resolve the given figure into triangles by drawing the lines — and —.

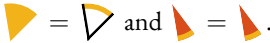
At the extremities of — make



again at the extremities of — make



in like manner make



Then — = —.

It is evident from the construction and (prop. I.32) that the figures are equiangular; and since the triangles

and — are equiangular;

then by (prop. VI.4),

$$\text{—} : \text{—} :: \text{—} : \text{—}$$

and — : — :: — : —

Again, because — and — are equiangular,

$$\text{—} : \text{—} :: \text{—} : \text{—}$$

\therefore ex æquali,

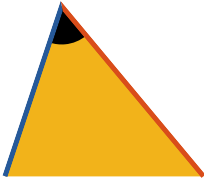
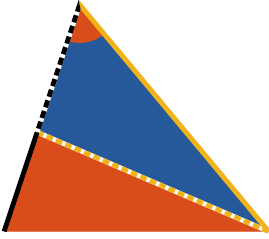
$$\text{—} : \text{—} :: \text{—} : \text{—} \quad (\text{prop. V.22})$$



In like manner it may be shown that the remaining sides of the two figures are proportional.









\therefore by (prop. VI.1)

— is similar to — and similarly situated; and on the given line —.

Q. E. D.



SIMILAR triangles ( and ) are to one another in the duplicate ratio of their homologous sides.

Let  and  be equal angles, and  and  homologous sides of the similar triangles  and  and on  the greater of these lines take  a third proportional, so that

$$\text{---} : \text{---} :: \text{---} : \text{---};$$





draw .

$$\text{---} : \text{---} :: \text{---} : \text{---} \quad (\text{prop. VI.4});$$

$$\therefore \text{---} : \text{---} :: \text{---} : \text{---} \quad (\text{prop. V.16}),$$

$$\text{but } \text{---} : \text{---} :: \text{---} : \text{---} \quad (\text{const.}),$$



$$\therefore \text{---} : \text{---} :: \text{---} : \text{---}$$

consequently  =  for they have the sides about the equal angles  and  reciprocally proportional (prop. VI.15);

$$\therefore \text{---} : \text{---} :: \text{---} : \text{---} \quad (\text{prop. V.7});$$











$$\text{but } \text{---} : \text{---} :: \text{---} : \text{---} \quad (\text{prop. VI.1}),$$

$$\therefore \text{---} : \text{---} :: \text{---} : \text{---},$$

that is to say, the triangles are to one another in the duplicate ratio of their homologous sides  and  (def. V.11).



Q. E. D.



SIMILAR polygons may be divided into the same number of similar triangles, each similar pair of which are proportional to the polygons; and the polygons are to each other in the duplicate ratio of their homologous sides.

Draw  and , and  and , resolving the polygons into triangles. Then because the polygons are similar,  = , and  :  ::  : 

\therefore  and  are similar,

and  =  (prop. VI.6);

but  =  because they are angles of similar

polygons; therefore the remainders  and  are equal;

hence  :  ::  : ,



on account of the similar triangles,

and  :  ::  : ,

on account of the similar polygons,





\therefore  :  ::  : ,





ex æquali (prop. V.22), and as these proportional sides

contain equal angles, the triangles  and  are similar (prop. VI.6).

In like manner it may be shown that the triangles











 and  are similar.

But  is to  in the duplicate ratio of  to  (prop. VI.19),





and  is to  in like manner, in the duplicate ratio of  to ;

\therefore  :  ::  :  (prop. V.11).






Again  is to  in the duplicate ratio of _____
 to _____, and  is to  in the duplicate
 ratio of _____ to _____.
 :  ::  :  ;
 ::  :  ;







and as one of the antecedents is to one of the
 consequents, so is the sum of all the antecedents to the
 sum of all the consequents; that is to say, the similar
 triangles have to one another the same ratio as the
 polygons (prop. V.12).

But  is to  in the duplicate ratio of _____
 to _____;
 \therefore  is to  in the duplicate ratio of
 _____ to _____.

Q. E. D.

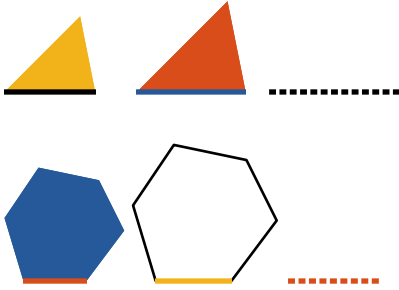


RECTILINEAR figures ( and )
 which are similar to the same figure ()
 are similar also to each other.

Since  and  are similar, they are equiangular, and have the sides about the equal angles proportional (def. VI.1); and since the figures  and  are also similar, they are equiangular, and have the sides about the equal angles proportional; therefore  and  are also equiangular, and have the sides about the equal angles proportional (prop. V.11), and are therefore similar.

Q. E. D.





I F four straight lines be proportional (— : — :: — : —), the similar rectilinear figures similarly described on them are also proportional.

And if four similar rectilinear figures, similarly described on four straight lines, be proportional, the straight lines are also proportional.

Part I.

Take a third proportional to — and —, and a third proportional to — and — (prop. VI.11);

since — : — :: — : — (hyp.)
— : :: — : (const.)

∴ ex æquali,

— : :: — :

but yellow triangle : orange triangle :: — : (prop. VI.20),

and blue pentagon : white pentagon :: — :

∴ yellow triangle : orange triangle :: blue pentagon : white pentagon (prop. V.11).



Part II.

Let the same construction remain;

$\triangle_{\text{yellow}} : \triangle_{\text{orange}} :: \text{pentagon}_{\text{blue}} : \text{hexagon}_{\text{white}} \text{ (hyp.),}$
 $\therefore \text{---} : \text{---} :: \text{---} : \text{---} \text{ (const.),}$
and $\therefore \text{---} : \text{---} :: \text{---} : \text{---}$
 (prop. V.11).

Q. E. D.



E QUIANGULAR parallelograms ( and ) are to one another in a ratio compounded of the ratios of their sides.

Let two of the sides  and  about the equal angles be placed so that they may form one straight line.

Since  +  = ,

and  =  (hyp.),







 +  = ,

and \therefore  and  form one straight line
(prop. I.14);

complete .




Since  :  ::  : 
(prop. VI.1),

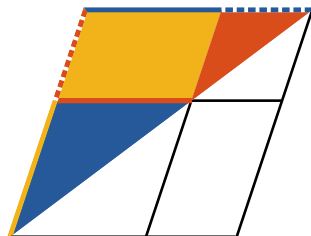
and  :  ::  :  (prop. VI.1),



 has to  a ratio compounded of the ratios
of  to , and of  to .

Q. E. D.



IN any parallelogram () the parallelograms ( and ) which are about the diagonal are similar to the whole, and to each other.





As  and  have a common angle they are equiangular;

but \therefore  \parallel 


 and  are similar (prop. VI.4),
 \therefore  :  ::  : 



and the remaining opposite sides are equal to those,

\therefore  and  have the sides about the equal angles proportional, and are therefore similar.

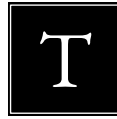
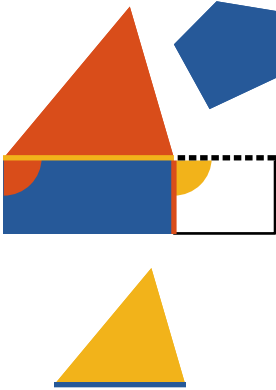
In the same manner it can be demonstrated that the

parallelograms  and  are similar.



Since, therefore, each of the parallelograms  and

 is similar to , they are similar to each other.




Q. E. D.





o describe a rectilinear figure, which shall be similar to a given rectilinear figure




() , and equal to another ().




Upon  describe  = ,

and upon  describe  = ,




and having  =  (prop. I.45),

and then  and  will lie in the same straight line (prop. I.14 and I.29).

Between  and  find a mean proportional  (prop. VI.13),

and upon  describe , similar to , and similarly situated.

Then  = .

For since  and  are similar, and  :  ::  :  (const.),

 :  ::  :  (prop. VI.20);




but  :  ::  :  (prop. VI.1);

\therefore  :  ::  :  (prop. V.11);

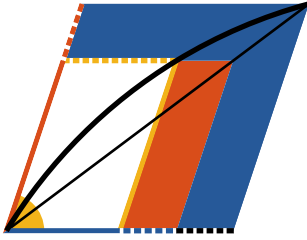
but  =  (const.),



and \therefore  =  (prop. V.14);

and  =  (const.);

consequently,  which is similar to  is also
 .

Q. E. D.







IF similar and similarly posited parallelograms ( and ) have a common angle, they are about the same diagonal.

For, if possible, let  be the diagonal of



and draw  \parallel  (prop. I.31).




Since  and  are about the same diagonal , and have  common, they are similar (prop. VI.24);

$$\therefore \text{orange} : \text{blue} :: \text{orange} : \text{blue};$$

but $\text{orange} : \text{blue} :: \text{orange} : \text{blue}$ (hyp.),

$$\therefore \text{orange} : \text{blue} :: \text{orange} : \text{blue},$$


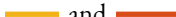



and $\therefore \text{blue} = \text{blue}$ (prop. V.9), which is absurd.

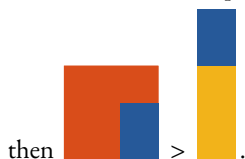
\therefore  is not the diagonal of  in the same manner it can be demonstrated that no other line is except .

Q. E. D.



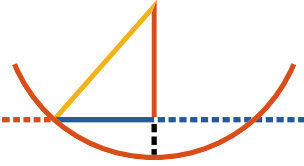
Of all the rectangles contained by the segments of a given straight line, the greatest is the square which is described on half the line.

Let  be the given line,
 and  unequal segments,
 and  and  equal segments;



For it has been demonstrated already (prop. II.5), that the square of half the line is equal to the rectangle contained by any unequal segments together with the square of the part intermediate between the middle point and the point of unequal section. The square described on half the line exceeds therefore the rectangle contained by any unequal segments of the line.

Q. E. D.



To divide a given straight line (— — — — —) so that the rectangle contained by its segments may be equal to a given area, not exceeding the square of half the line.

Let the given area be = — — — — —².

Bisect — — — — —, or make — — — — — = — — — — —;

and if — — — — —² = — — — — —²,

problem is solved.

But if — — — — —² ≠ — — — — —²,

then must — — — — — > — — — — — (hyp.).

Draw — — — — — ⊥ — — — — — = — — — — —;

make — — — — — = — — — — — or — — — — —;

with — — — — — as radius describe a circle cutting the given line; draw — — — — —.

Then — — — — — × — — — — — + — — — — —² = — — — — —² (prop. II.5)
= — — — — —².

But — — — — —² = — — — — —² + — — — — —² (prop. I.47);

∴ — — — — — × — — — — — + — — — — —² = — — — — —² + — — — — —²,

from both, take — — — — —²,

and — — — — — × — — — — — = — — — — —².

But — — — — — = — — — — — (const.),

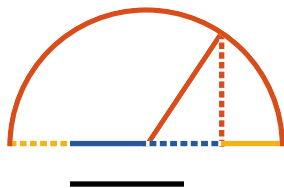
and ∴ — — — — — is so divided that

— — — — — × — — — — — = — — — — —².

Q. E. D.



To produce a given straight line (— · · · · ·),
so that the rectangle contained by the segments
between the extremities of the given line and
the point to which it is produced, may be equal
to a given area, i. e. equal to the square on ———.



Make — = · · · · ·,
and draw · · · · · \perp · · · · · = ———;
draw ———;

and with the radius ———, describe a circle meeting
— · · · · · produced.

Then

$$\text{—} \cdot \cdot \cdot \cdot \cdot \times \text{—} + \cdot \cdot \cdot \cdot \cdot^2 = \text{—}^2$$

(prop. II.6) = ———².

But ———² = · · · · ·² + · · · · ·² (prop. I.47)

$$\therefore \text{—} \cdot \cdot \cdot \cdot \cdot \times \text{—} + \cdot \cdot \cdot \cdot \cdot^2 =$$

$$\cdot \cdot \cdot \cdot \cdot^2 + \cdot \cdot \cdot \cdot \cdot^2,$$

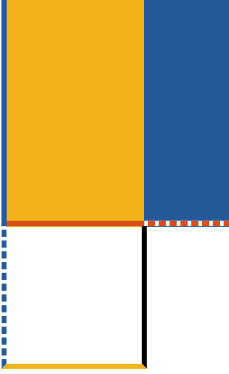
from both take · · · · ·²,

and $\therefore \text{—} \cdot \cdot \cdot \cdot \cdot \times \text{—} = \cdot \cdot \cdot \cdot \cdot^2$


but · · · · · = ———,

$$\therefore \cdot \cdot \cdot \cdot \cdot^2 = \text{the given area.}$$

Q. E. D.



o cut a given finite straight line (— — — —) in extreme and mean ratio.

On — — — — describe the square  (prop. I.46);

and produce , so that

$$\text{— — — —} \times \text{— — — —} = \text{— — — —}^2 \text{ (prop. VI.29);}$$

take  = ,

and draw  || ,




meeting  ||  (prop. I.31).




Then  =  \times , and is

$$\therefore = \text{— — — —} \text{— — — —};$$

and if from both these equals be taken the common part




 , which is the square of ,

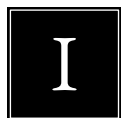
will be = , which is =  \times ;

that is  2 =  \times ;

\therefore  :  ::  : ,



and  is divided in extreme and mean ratio
(def. VI.3).

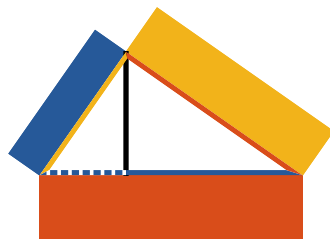
Q. E. D.




If any similar rectilinear figures be similarly described on the sides of a right angled triangle



() the figure described on the side () subtending the right angle is equal to the sum of the figures on the other sides.



From the right angle draw  perpendicular to



then

$$\text{---} : \text{---} :: \text{---} : \text{---}$$

(prop. VI.8).

$$\therefore \text{---} : \text{---} :: \text{---} : \text{---}$$

(prop. VI.20).

but $\text{---} : \text{---} :: \text{---} : \text{---}$

(prop. VI.20).

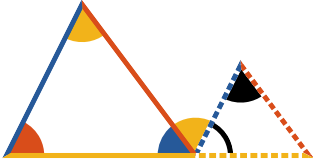
Hence $\text{---} + \text{---} : \text{---} ::$









$$\text{---} + \text{---} : \text{---};$$

but $\text{---} + \text{---} = \text{---};$

and $\therefore \text{---} + \text{---} = \text{---}.$

Q. E. D.



I F two triangles ( and ) have two sides proportional ( :  ::  : ), and be so placed at an angle that the homologous sides are parallel, the remaining sides ( and ) form one right line.





Since  || ,

 =  (prop. I.29);

and also since  || ,

 =  (prop. I.29);








\therefore  = ;



and since  :  ::  :  (hyp.),

the triangles are equiangular (prop. VI.6);







\therefore  = ;









but  = ;














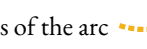
\therefore  +  +  =  +  +  =  (prop. I.32),




and \therefore  and  lie in the same straight line (prop. I.14).






Q. E. D.





In equal circles ( , ), angles, whether at the centre or circumference, are in the same ratio to one another as the arcs on which they stand ( :  ::  : ); so also are sectors.

Take in the circumference of  any number of arcs  ,  , etc. each =  , and also in the circumference of  take any number of arcs  ,  , etc. each =  , draw the radii to the extremities of the equal arcs.

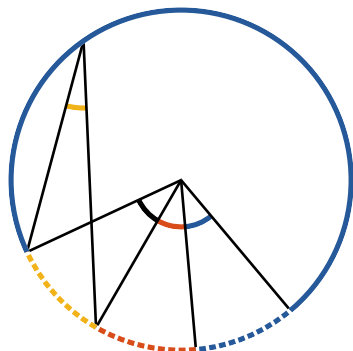
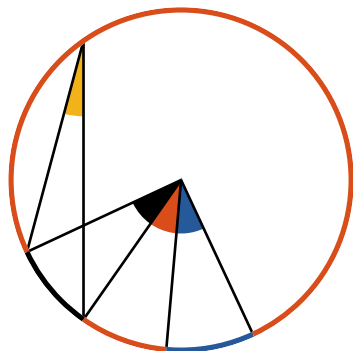
The since the arcs  ,  ,  , etc. are all equal, the angles  ,  ,  , etc. are also equal (prop. III.27); \therefore  is the same multiple of  which the arc  is of  ; and in the same manner  is the same multiple of  , which the arc  is of the arc .

Then it is evident (prop. III.27), if  (or if m times ) $>$, $=$, $<$  (or n times

)
then  (or m times )
 $>$, $=$, $<$  (or n times );

\therefore  :  ::  :  (def. V.5), or the angles at the centre are as the arcs on which they stand; but the angles at the circumference being halves of the angles at the centre (prop. III.20) are in the same ratio (prop. V.15), and therefore are as the arcs on which they stand.

It is evident, that sectors in equal circles, and on equal arcs are equal (prop. I.4, III.24 and III.27 and def. III.9).





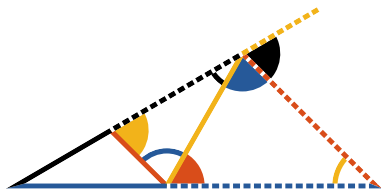
Hence, if the sectors be substituted for the angles in the above demonstration, the second part of the proportion will be established, that is, in equal circles the sectors have the same ratio to one another as the arcs on which they stand.

Q. E. D.






If the right line (— · — · — ·) bisecting an external


angle  of the triangle 



meet the opposite side (—) produced, that whole produced side (— · — · — ·), and its external segment (— · — · — ·) will be proportional to the sides (— · — · — · and —), which contain the angle adjacent to the external bisected angle.

For if — be drawn \parallel — · — · — ·,
then  = , (prop. I.29);

= , (hyp.),

= , (prop. I.29);

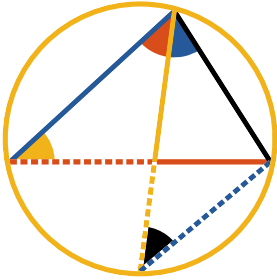
and \therefore — · — · — · = —, (prop. I.6),

and — · — · — · : — :: — · — · — · : — · — · — · (prop. V.7);









But also, — · — · — · : — · — · — · :: — · — · — · : — · — · — ·
(prop. VI.2);





and therefore — · — · — · : — · — · — · :: — · — · — · : —
(prop. V.11).



Q. E. D.





IF an angle of a triangle be bisected by a straight line, which likewise cuts the base; the rectangle contained by the sides of the triangle is equal to the rectangle contained by the segments of the base, together with the square of the straight line which bisects the angle.

Let  be drawn, making  =  ;
then shall  ×  =  ×  + ².

About  describe  (prop. IV.5),
produce  to meet the circle, and draw .

Since  =  (hyp.),

and  =  (prop. III.21),

∴  and  are equiangular (prop. I.32);

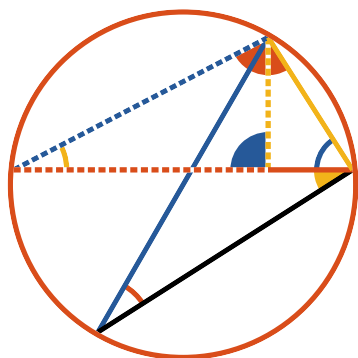
∴  :  ::  :  (prop. VI.4);
∴  ×  =  ×  (prop. VI.16)
=  ×  + ² (prop. II.3);





but  ×  =  ×  (prop. III.35);
∴  ×  =  ×  + ²

Q. E. D.






From any angle of a triangle a straight line be drawn perpendicular to the base; the rectangle contained by the sides of the triangle is equal to the rectangle contained by the perpendicular and the diameter of the circle described about the triangle.



From  of 
draw  \perp ;

then shall  \times  =  \times the diameter
of the described circle.

Describe  (prop. IV.5), draw its diameter

, and draw ;

then \therefore  =  (const. and prop. III.31);

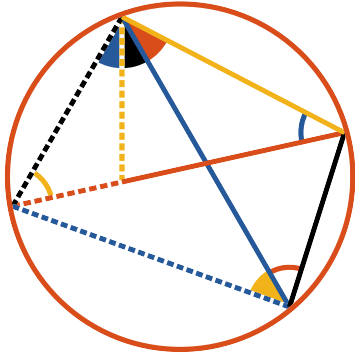
and  =  (prop. III.21);

\therefore  is equiangular to  (prop. VI.4);


\therefore  :  ::  : ;

and \therefore  \times  =  \times 
(prop. VI.16).

Q. E. D.



THE rectangle contained by the diagonals of a quadrilateral figure inscribed in a circle, is equal to both the rectangles contained by its opposite sides.

Let  be any quadrilateral figure inscribed in



and draw  and ;

then  \times  =

 \times  +  \times .

Make  =  (prop. I.23),

\therefore  = ; and  =  (prop. III.21);

\therefore  :  ::  :  (prop. VI.4);

and \therefore  \times  =  \times 

(prop. VI.16);

again, \therefore  =  (const.),





and  =  (prop. III.21);

\therefore  :  ::  :  (prop. VI.4);

and \therefore  \times  =  \times 

(prop. VI.16);

but, from above,

 \times  =  \times ;

\therefore  \times  =

 \times  +  \times  (prop. II.1).

Q. E. D.

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