Contents

Prologue

I: AUTHOR

Alexandria: The geometer and the king
Elephantine: Pot shards
Hypsicles: The fourteenth book
Theon of Alexandria: Editing the Elements
Stephanos the scribe: Euclid in Byzantium
Al-Hajjaj: Euclid in Baghdad
Adelard: The Latin Euclid
Erhard Ratdolt: Printing the Elements
Marget Seymer her hand: Owning the Elements
CONTENTS

Edward Bernard: Minerva in Oxford  81

Interlude  91

II: SAGE

Plato: The philosopher and the slave  95
Proclus Diadochus: Minerva in Athens  102
Hroswitha of Gandersheim: Wisdom and her daughters  107
Rabbi Levi ben Gershom: Euclid in Hebrew  114
Christoph Clavius: The Jesuit Elements  123
Xu Guangqi: Euclid in China  133
Blame not our author: Geometry on stage  145
Baruch Spinoza: The geometrical manner  151
Anne Lister: Improving the mind  161

Interlude  169

III: HERO

Petechonsis: Taxing and overtaxing  173
Dividing the monochord  179
Hyginus: Surveying the land  186
CONTENTS

Muhammad Abu al-Wafa al-Buzjani:
Dividing the square 193

Lady Geometria: Depicting the liberal arts 202

Piero della Francesca: Seeing in perspective 212

Euclid Speidell: Teaching and learning 225

Isaac Newton: Mathematical principles 230

Interlude 237

IV: SHADOW AND MASK

Mary Fairfax: Euclid and the straitjacket 241

François Peyrard: Manuscript 190 249

Nicolai Ivanovich Lobachevskii: Parallels 260

Maggie and Tom: The torture of the mind 269

Simson in Urdu: The Euclidean empire 278

His modern rivals 285

Thomas Little Heath: The true con amore spirit 291

Max Ernst: Euclid’s mask 300

Euclidean designs 306

Lambda: Curved space, dark energy 316

Epilogue 322

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## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgements</td>
<td>325</td>
</tr>
<tr>
<td>Image Credits</td>
<td>327</td>
</tr>
<tr>
<td>Notes on Sources</td>
<td>331</td>
</tr>
<tr>
<td>Select Bibliography</td>
<td>355</td>
</tr>
<tr>
<td>Index</td>
<td>389</td>
</tr>
</tbody>
</table>
I

Author
Alexandria

The geometer and the king

Alexandria, around 300 BC.

A dinner, say: a symposium, in the palace quarter, perhaps in the Museum. Ptolemy himself in attendance: general, hero, king, deity. And the talk touches on geometry: why so hard? Why is there no easier way? The geometer – a dusty man, but pert – answers: Majesty, there is no royal road to geometry.

Ptolemy snubbed is one of the irresistible stories. The man had been a childhood friend of Alexander the Great; one of his bodyguard. Maybe his illegitimate half-brother. He was a trusted general (the name is said to mean ‘warlike’): level-headed but capable of the grand gesture; a man of no nonsense.

He was one of the great survivors, too. In the twenty years of chaos that followed Alexander’s death, when many abler men died, Ptolemy played and won. Of all the successors who eventually carved up Alexander’s brief, continent-spanning empire, he founded the longest dynasty, the stablest country. He chose Egypt, and he
never risked it for a larger realm. Fourteen Ptolemaic rulers followed him, until Cleopatra lost it all at the Battle of Actium 250 years later. The first king, then, of the last Egyptian dynasty. Basileus to the Greeks, pharaoh to the Egyptians. Inheritor of 3,000 years of Egyptian kingship and, yes, a god too. In 306 BC he defeated an attack on Rhodes so soundly that altars were erected to him and he acquired the title ‘saviour’. By 278 BC there were Ptolemaic games in his honour: four-yearly, like the Olympics.

The geometer, by contrast – a man named Euclid; Eukleídēs – is utterly obscure, historically speaking. The story about the ‘royal road’ is moonshine, sadly; it is also told about another geometer (Menaechmus) and another king (Alexander), and there is little
reason to suppose it really happened. Even his dates – sometime
around 300 BC – are the mere surmise of authors writing centuries
after him. Unlike the exceptionally well-documented Ptolemy, Euclid
left no biographical traces whatever. He founded no dynasty, built
no palaces. His legacy was solely intellectual.

But what a legacy. The line of his students at Alexandria outlasted
his life. His book outlasted his civilisation.

What was this city, that produced such a man and such a book?
Alexandria was the right setting for the *Elements of Geometry*. It
was Ptolemy’s greatest achievement. Alexander himself decreed the
city, on the site of what had been a village and, like a dozen others,
it bore his name. He never saw a stone erected, but Ptolemy took it
for his capital, moving the Egyptian royal seat from Memphis. It was
a Greek *polis* in a profoundly un-Greek world, a new foundation in
a land where cities were 2,000 years old. Ptolemy did everything to
make it splendid; it had an assembly, a council, its own coinage and
its own laws. There were broad boulevards, colonnades, avenues of
trees, street lamps. In 322 BC he kidnapped Alexander’s corpse and
put it on display in his new royal city.

It was indeed the most splendid site for a city, at the meeting
place of two continents, just to the west of the mouths of the Nile.
It would be a major commercial port for centuries, a strategic
military site until the Second World War. Ptolemy laid the founda-
tions of the famous lighthouse: fortress and beacon, it would be
one of the seven wonders of the world when it was done, 400 feet
high and topped by a statue of Zeus. It stood for 1,500 years.
Blessed with such a city, people immigrated from all over the Greek
world, and Alexandria became not just notoriously big and splen-
did but notoriously crowded and cosmopolitan, with Greeks, 
Macedonians, Egyptians, Jews, Syrians and more, its streets teeming
like ant heaps. Within a few generations it would have more than
a million inhabitants.

As well as town planning, and the sheer erection of building
upon building, Ptolemy involved himself in cultural policy: and with his characteristic effectiveness. To make himself a convincing Egyptian pharaoh, he indulged in sculpture to match, and devised a new cult of ‘Serapis’, a blatantly invented figure with a hybrid iconography. Like all his achievements, it endured: the temple, the Serapeum at Alexandria, stood for 600 years.

And to please the Greek mind and heart there were pageants, festivals, and a palace with tapestries the gods would prize. As one contemporary put it, Alexandria had ‘wealth, wrestling schools, power, tranquillity, fame, spectacles, philosophers, gold, youths, the sanctuary of the sibling gods . . . the Museum, wine, every good thing [one] could desire’.

All of which was invaluable in projecting Greek power and an idea of Greekness in a profoundly alien environment; in saying, this is what we do in the great Greek world. This is our right to rule.

And so, the Museum. The Mouseion: the shrine of the Muses. It was royally subsidised, with scholars in discipline after discipline. Their head was a priest of the Muses, and they included poets, grammarians, historians, philosophers, doctors, natural philosophers, geographers, machine-builders, astronomers, and of course geometers. It was partly Ptolemy’s own impulse, partly the creation of Demetrios of Phaleron, a famous pupil of Aristotle brought over from Athens to oversee the creation of the new institution. It had courts, covered walks and gardens, a dining hall and an observatory. The staff numbered perhaps forty, and they spent their time researching, writing and sometimes teaching. They held learned symposia, some attended by the king. They were a remarkable collection of people, sometimes compared a little sourly with the collection of animals that Ptolemy also founded: ‘well-fed bookworms, arguing endlessly in the Muses’ birdcage’. If there were bookworms, there were certainly books, too; the library at Alexandria would become the most famous in the world, though it seems to have been organised a little later, under Ptolemy’s son.
All of which is how the famous Greek mathematician ended up working in Egypt. Was Euclid another part of Ptolemy’s collection, someone brought in to swell the ranks of the Museum? It is not certain whether he was native to Alexandria or an immigrant, although at this early date in the city’s life the latter is much the more likely. An immigrant from where? His austere prose gives no hint of an accent: unlike Archimedes, in the next generation, who wrote in the Doric dialect of Syracuse.

What came to Alexandria in Euclid’s person (and perhaps in the persons of other mathematicians; it is not clear whether or not he was the only one) was a well-established tradition of Greek geometry. Greeks liked to have things to think about. They liked hobbies. Some Greeks raced chariots, some talked about philosophy, some occupied themselves with politics. From perhaps the late fifth century BC onwards, some did geometry.

What was it like? Perhaps it is clearest to think of Greek geometry as an outgrowth of the Greek love of talk, of disputation. For its geometry was nothing if it was not a performance.

Draw a line, a square, a circle. Reason out loud as you draw; play to the inevitable audience. From such beginnings the long-lived game of geometrical reasoning took shape. The figure of the geometer drawing in the sand remains part of the image of ancient Greek mathematics to this day: raking in the ‘learned dust’, as the Roman orator Cicero put it. He memorably evoked Archimedes as a man of ‘dust and drawing-stick’. (Though have you ever tried to draw a detailed diagram in dry sand? Pieces of clay, wax tablets or, for showing to a larger audience, wooden boards seem more probable.)

The number of Greek mathematicians was never very large, and they had to write their ideas down to preserve what they had found out about their lines and circles; there weren’t enough of them, it seems, for a purely oral transmission to stand a chance. So a genre was born: a special style of mathematical writing. That style would
come to define mathematics in the West for more than two millennia, as constraining as any poetic metre, and as long-lived. Its components were the statement (of something to be proved); the diagram, with its points labelled with letters; and a chain of reasoning from things already known to things newly proved. That chain ended with the proposed, intended result, and the section – the ‘proposition’ – was rounded off with the note that ‘this is what was to be proved’: ἥπερ ἐδείξαί; quod erat demonstrandum; QED. In some cases it was ‘what was to be drawn’. Here is an example:

How to draw an equilateral triangle

Start with any straight line; call its ends A and B.

Now draw two circles, each with its radius equal to that line: one centred at A, the other centred at B.

The two circles will cross at two points. Pick one of them and call it C. Now join up A, B and C. They make an equilateral triangle.

Why?

Because of the way the distance from A to B was used to find C. C is that same distance from A, and C is also that same distance from B. In other words, all three of the triangle’s sides – AB, BC and CA – are the same length. So it’s an equilateral triangle. Which is what was to be drawn.

The same ancient sources that report when Euclid lived also report that there were written collections of geometrical learning in Greek by perhaps 400 BC: a century before him. They are quite informative about the subjects involved, and even some of the specific results and techniques. The written matter itself has not survived, though, throwing it all into doubt. There is a strong temptation to make up genealogies for mathematical ideas when real evidence is lacking. So yes, maybe the study of the circle was
done by the Pythagoreans; likewise the work on numbers and their properties. Very probably the work on ratios was done by a geometer called Eudoxus early in the fourth century BC. Some work on the regular solids originated with another, named Theaetetus. The claim that there were, before Euclid, well-developed books called \textit{Elements of Geometry} seems distinctly more doubtful.

What was Euclid’s role, then? He took all the easier material known to the Greek geometers of his day and put it all together in a single book. He organised it, both on the large scale and the small. Certainly he added some new matter of his own, though no one can now confidently identify what was new and what was not. Historians continue to argue – and they always will – about how much was compilation and how much composition in Euclid’s book. His was a work of collection, like Ptolemy’s; Euclid the
Museum artefact became himself a curator, the *Elements* a smaller museum.

Yet this museum contained a world. It displayed the geometrical style of prose, in a relentless, ritualistic tramp of proposition after proposition: 400 of them, arranged in thirteen ‘books’ or chapters. Every verb was perfect, imperative and passive: ‘let a circle have been drawn’. There was something hypnotic about it; something infinitely calm. The book began with definitions: what was meant by a line? A point? A circle? It continued with the simplest manipulations of lines and shapes in two dimensions: how to draw different kinds of triangle; how to divide a line or an angle in two. The fact that, in a triangle, any two sides add up to more than the third. The Epicurean philosophers thought that last piece of geometrical information was ‘evident even to an ass’ since ‘if straw is placed at one extremity of the sides, an ass in quest of provender will make his way along the one side and not by way of the two others’.

Euclid did not care how obvious any of it was. He arranged and exemplified a toolbox of the basic techniques and results that he had inherited: ways of arguing, ways of proving; facts that geometers commonly assumed or used but seldom proved in full. At the end of the first book he placed ‘Pythagoras’ theorem’. Draw a triangle, with one of its angles a right angle. Using its shortest side as a base, draw a square, whose side is the same length as that side of the triangle. Repeat the procedure with the triangle’s two longer sides, so that you end up with three squares of different sizes, resting flush against the three sides of the triangle. Now, it turns out, the areas of the two smaller squares will add up to that of the larger one: a startling fact, not evident to any ass, which Euclid proved in his characteristically meticulous manner.

And so the ideas and the diagrams became harder and more complicated throughout the book. There were purely geometrical sections: a description of how to draw a regular pentagon or hexagon inside a given circle, for example. Parts of the book dealt
not with geometry but with numbers and ratios, ranging from the most basic facts (‘if an odd number is multiplied by an odd number, then the product is odd’) to a procedure for finding the mysterious ‘perfect’ numbers, equal to the sum of their divisors.

Finally, Euclid turned to three-dimensional shapes. The last three books of the *Elements* – books 11, 12 and 13 – were concerned with spheres, cones and cylinders, with cubes and cuboids and with the regular polyhedra. These were beautiful solids whose faces were all the same regular polygon: triangles, squares or pentagons. There were just five regular polyhedra: the tetrahedron (four triangular faces), the cube, the octahedron (eight triangles), the dodecahedron (twelve pentagons) and the icosahedron (twenty triangles). He showed how to make such shapes, starting from, say, a given triangle or a given circle; he showed how to find their surface areas and their volumes. Euclid’s explorations in these final books were frequently ingenious, and sometimes applied an almost unbelievable amount of lateral thinking. Despite its gentle beginnings, and its incorporation of a lot that anyone could understand, the *Elements* as a whole was a virtuoso performance; a road that only the keenest of geometrical minds could follow all the way.

It added up to more than 20,000 lines of text in Greek. Euclid was careful, but he was no superman, and both joins and slips were sometimes visible. A few definitions (oblong, rhombus, rhomboid) seemed to have been carried across from older sources but never actually used. Quite a number of terms were used that were, conversely, not defined earlier on. Some words were ambiguous. A surprising amount was taken for granted about the properties of points and lines that Euclid never explicitly set out in his assumptions. Some propositions were merely special cases of others; some propositions were, strictly speaking, unnecessary because they were the mere logical consequences of others. But despite such wrinkles, the *Elements* was a fine, even an awe-inspiring monument to all that had been done in Greek geometry so far.
Euclid was by no means the author of just one book. The order of events is not clear, but it is certain that he wrote more. There were perhaps four other books on special topics in elementary geometry, and there were books on the applications of mathematics – to music, astronomy, optics and more – as well. In total nearly a dozen books are mentioned in the early evidence; eight actual texts survive, though most are disputed by historians.

Back in seething Alexandria, where the building work is still going on and the streets are ever more crowded. By the end of Euclid’s life the great lighthouse at Pharos has been built (did the architects consult Euclid? It would be intriguing to think so); the library and Museum are nearing completion and the palace complex is grander than ever. The Elements is finished: thirteen rolls of papyrus covered with neat columns of text and diagrams. And Euclid is still teaching, still taking on new students.

One beginner is impatient, like the king before him. After he has understood the first proposition he bursts out, ‘What is my profit now that I have learned that?’

A glance of contempt, or perhaps of pity. Euclid calls for a servant. ‘Give him threepence, since he must always make a profit out of what he learns.’

Another romantic legend, perhaps: one that circulated later in Greece, during its period of Roman domination. Like the ‘royal road’ story, it helped to protect Euclid from the whiff of servility, of sycophancy that hung over anyone connected with Ptolemaic Alexandria and its institutions. It preserved and dramatised the idea that geometry was a leisured, cultured pursuit, part of the life of the mind. Not a profitable trade, but pure, truthful and beautiful for its own perfect sake.

Some 350 geometrical propositions in the driest of styles. It’s an
odd thing, to have become one of the most enduring cultural artefacts of the Greek world. Ptolemaic Alexandria is largely dust today; a few wrecked statues are dug from the ground or pulled from the sea from time to time, but the splendour is all gone. Ptolemy’s dynasty died with Cleopatra. The library is scattered. But the books – the *Elements* among them – the books lived.
Index

Abbasid dynasty, 2, 48–53
Académie des Sciences (France), 254–5
Actium, Battle of (31 BC), 8, 32
Adela, Countess of Chartres, 205
Adelard of Bath, 56, 57–62, 58, 63, 126, 205, 206
Agrippa, Heinrich Cornelius, 251
Alberti, Leon Battista, 214, 216, 218, 219, 221
Albertus Magnus, 126
Alexander the Great, 7–8, 9, 54, 181
Alexandria: cosmopolitanism, 9, 32; as crowded, 9, 16; fire (47 BC), 32; library at, 10, 16, 17, 26, 27, 28, 30, 31, 32–3, 317; Museum (Mouseion), 10–11, 16, 31, 32; music in, 179, 181; no preserved papyri from, 19; ‘no royal road to geometry’ story, 7, 8–9, 16, 27; Persian conquest of (619), 40; Pharos lighthouse at, 9, 16; Ptolemaic city as dust today, 17; reputation for mob violence, 32, 37–8; Roman period, 16, 31, 32, 37–8; splendour and grandeur of, 1, 9–10, 27, 32; and survival of Greek literature, 32–3; temple of Serapis, 10, 37; town planning/architecture, 1, 9–10, 16, 32
Alfonsi, Petrus, 60–1
algebra, 81, 163, 195, 217, 275, 288; and Descartes, 231; and Mary Fairfax (Somerville), 246, 247; and Heath, 296; Lobachevskii’s language, 264–5, 266, 267, 268; and Newton, 231–3, 234
Analytical Society, 286
Antioch, 59
Apollonius, 28, 29, 42, 84, 87, 162, 295
Aquinas, Thomas, 126
Arabic language: and Al-Buzjani’s work, 195, 196, 198; Arabic translations of Elements, 51–2, 53–5, 56, 59–63, 85, 197, 257, 258–9, 281, 297; and Elements in Oxford, 81, 83, 85; Fihrist (literary index/encyclopaedia), 194; first wave of translations
into, 51–2, 53–5, 257; and
Jewish culture, 116, 117, 118;
and the ‘parallel postulate,’ 115;
and ‘practical’ mathematical
problems, 217; and preservation
of Greek learning, 51–5, 57, 166,
257, 258–9, 297; translations
from, 56, 57, 59–63, 140, 281;
and vocabulary of science, 53–4
Archimedes, 11, 27, 42, 162, 177,
198, 251, 252, 295
architecture: Chartres Cathedral, 2,
202–5, 207; in China, 136–7; in
Greece, 307; in Greek
Alexandria, 1, 9–10, 16, 32;
Islamic, 198–201, 315;
perspectiva in Renaissance,
213–14
Arcimboldo, Giuseppe, 303
Arethas of Patras, 43–7
Aristaeus, 29
Aristophanes, 176–7
Aristotle, 10, 33, 183, 204; Arabic
translations of, 51, 54; Arethas
of Patras’ book collection, 43,
45, 46; and Jewish culture, 116,
118; Latin world’s rediscovery of,
127; logic, 116, 127, 128, 152;
and mathematical ideas, 97, 103,
120, 127, 294
Aristoxenus, 40
arithmetic, 40, 62, 131, 191, 296;
Al-Buzjani’s work on, 195–6; and
Boethius, 108, 205; books 7–9 of
Elements, 76, 120, 183–4; Gougu
yi (Chinese methods), 142;
Pacioli’s book on, 222;
personifications of, 204, 205;
teaching of, 217, 227, 228–9
Arsinoë (modern Faiyum), 19–20
artists: as craftsmen in early
Renaissance Italy, 217;
perspectiva in Renaissance,
213–14, 216, 218–20, 223–4;
repurposing of Euclidean
geometry, 306–15; surrealist, 302,
303
Asquith, H. H., 293
Association for the Improvement of
Geometrical Teaching, 287
astrology, 59, 119, 209, 210–11, 231
astronomy: Adelard’s interest in, 58,
59, 60–1; and al-Buzjani, 195,
196; al-Khwarizmi’s tables, 59,
60–1, 195; and ben Gershom,
118–19, 120; and Edward
Bernard, 84; and Byzantine
scholarship, 40, 42; Claudius
Ptolemy’s Almagest, 35, 51; and
Clavius, 125–6, 131; dark energy,
319–20; and depictions of Euclid,
209, 210, 210–11; Eratosthenes
and size of the earth, 28;
Euclidean Phaenomena, 180,
305; expanding universe, 318–21;
and Mary Fairfax (Somerville),
246, 247; Hypsicles and stars,
29; Indian, 51, 280–1; and
Newton, 234; parallax of stars,
265; personified at Chartres, 204;
and Proclus, 104, 180; and
Claudius Ptolemy, 31, 35, 40, 42,
51; and Theon, 31, 34, 38; and
Xu Guangqi, 142, 143
Athens: and the Elements, 21,
99–101, 103–6; Plato’s Academy,
99; Plato’s circle in, 97–8;
playwrights, 26, 27, 33, 176–7,
181; revived Platonic Academy,
102–6; and ‘seven liberal arts,’
40; veiled figure of Euclid legend,
95, 100–1, 305
Augsburg, 66, 73–4
Averroës (Ibn Rushould), 118
Avicenna (Ibn Sina), 55, 194
Babylonia, 29, 175
Baghdad: Abbasids move capital to
INDEX

(762), 49; Banu Musa, 53, 55; as cultural centre, 50–1, 52–5; culture of meeting and discussions, 196, 200–1; Indian and Persian learning, 51, 54; library ('House of Wisdom'), 52–3, 59; revival under Buyid dynasty, 193–201; Round City of al-Mansur, 48, 49–55, 50; translations of the Elements in, 2, 51–2, 54–5; war of succession in (196 AH, AD 811), 52

Banks, J. Cleaver, 46
Barmakid family, 49
Barrow, Isaac, 231–2, 233, 234
Bartels, Johann Christian Martin, 262
Basilides of Tyre, 29
Beijing, 2, 133, 134, 135, 136–43
Bellman, Carl Mikael, 243
Benedict XII, Pope, 119
Benedictine order, 110–11
Berkeley, Bishop, 152
Bernard (brother of Thierry), 205
Bernard, Edward, 83–7, 89
Billingsley, Henry, 76–7
Blake, William, 242–3, 244
‘Blame not our author’ (play), 145–50
Bodleian Library (Oxford), 47, 81, 82–3, 86–7, 209
Boethius, 58, 62, 108, 112, 126, 191, 205–6, 207
Bonnycastle, John, 246
‘Bourbaki’ (group of French mathematicians), 304


British Association for the Advancement of Science, 290
British East India Company, 280
British Library (London), 207
Brunelleschi, Filippo, 213, 214
Buddhism, 137, 140
Bulgarian khanate, 42
Busby, Richard, 228
Buyid dynasty, 193–201
al-Buzjani, Muhammad Abu al-Wafa, 193, 194–201, 314
Byrne, Oliver, 309–11
Byzantium: cultural contact with caliphate, 50–1, 53; founding of Constantinople (324), 39–40; Latins take Constantinople (1204), 57; and New Testament, 256; ninth-century cultural revival, 42–3; scholarship, 40–6, 256, 296; wars and internal conflicts, 42, 49

Caesarea, 43
calculus, 234, 247, 263, 275
caliphate: Abbasid dynasty, 2, 48–53; break-up of empire from later ninth-century, 194; cultural contact with Byzantium, 50–1, 53; Fatimid library (Cairo), 57; rule in Alexandria, 40; sale or plunder of Islamic libraries, 57; scholarship and learning, 51–5; vast world ruled by, 48–9; war of succession in Baghdad (196 AH, AD 811), 52; war with Byzantium, 42
Cambridge University, 230, 231–2, 234, 244–5, 290, 291–2
camera obscura, 118
Campanus of Novara, 63–4, 69, 76
Carolingian empire, 42, 189
Carroll, Lewis: Euclid and His Modern Rivals, 285, 287; Through the Looking Glass, 302
cartographers and navigators, 264
Cassiodorus, 188, 192
Cattaneo, 134–5
Cayley, Arthur, 287
Chang’an (Tang city), 52
Chapone, Hester, 245
Charles the Bald, 205
Chartres Cathedral, 2, 202–5, 207
Chatterjee, Rimi, 283–4
Chesterfield, Lord, 244
China, 133–44, 295
Christianity: and Abbasid caliphate, 49, 50, 51, 53; Chartres Cathedral, 2, 202–5, 207; Constantine’s conversion to (312), 37; early thinkers and writers, 43, 111, 126, 129; exiled papacy in Avignon, 116, 119; and Hadrian, 108–9; influence of the Platonists, 126, 129; and new model of ‘geometry,’ 191–2; New Testament, 207, 256; and Newtonian approach, 235; Old Testament, 192, 256; papacy, 42, 116, 119, 124–5, 126; reconquest of Spain, 57; sortes Biblicae, 209
see also Jesuit order (Society of Jesus)
Cicero, 11
Claudius Ptolemy, 31, 34, 40, 42, 51, 69
Clavius, Christoph, 123–6, 125, 129–32, 135, 139, 140–1, 143, 147–8, 153
Clement VI, Pope, 119
Cleopatra, 8, 17
Clifford, William Kingdom, 288
codices, 41
Coimbra, University of (Portugal), 124, 125, 136
Coleridge, Samuel Taylor, 273
compasses, pairs of, 207
Confucianism, 134, 137
conic sections, 28, 42, 276
Constantine, emperor, 37
Constantinople, 39–40, 42, 57
Conway, Lady Anne, 164
Copernicus, 118, 127
Corpus agrimensorum, 188–91, 190, 205
crusades, 57, 59
cubes, 15, 30, 36, 61, 97, 220
Cuomo, Serafina, 23
dark energy, 319–20
al-Dawla, Sharaf, 195, 196
Daylam region, 194
De Morgan, Augustus, 287
Dee, John, 77
Delambre, Jean Baptiste Joseph, 251, 254
Demetrius of Phaleron, 10
Deneau, Nathaniel, 225, 229
descartes, René, 153–5, 156, 159, 231
Dictionary of Scientific Biography, 36
dodecahedrons, 15, 28, 28–30, 36, 97
drama, 2, 107–13, 120, 145–50
Düren, Albrecht, 222–3, 244
education: in British India, 278, 279, 281–2, 283–4; Oliver Byrne’s theories, 309; Elements as difficult/boring to study, 243, 286; in Eliot’s The Mill on the Floss, 269–73, 274, 275–7; Euclid’s dominance in English-speaking world, 163, 269–74, 276, 277, 279–80, 286–90; Euclid’s official demotion in Britain, 289–90, 296–7, 298–9, 316–17; and the Jesuits, 126, 130–2; John Perry’s agenda, 289–90; in revolutionary France, 249, 250–2; ‘school’ editions of Euclid, 279–80; ‘seven liberal arts,’ 40, 184, 204–9; in
Victorian/Edwardian Britain, 269–74, 275–7, 279–80, 286–90, 296–9; and women, 241–2, 245–8, 272–3, 274–6, 277

Egypt: Elephantine island, 18, 22; land measurement and taxation, 173–6; Nile Valley, 19; papyrus fragment finds, 19–20, 22; Ptolemaic rulers, 7–8, 17, 32, 175; Roman period, 16, 31, 32, 37–8; ‘Teaching of Amenemope,’ 175 see also Alexandria

Einstein, Albert, 267–8, 319

Elements of Geometry: and algebraic proofs, 81, 163, 231–3, 296; Arabic translations of, 51–2, 53–5, 56, 59–63, 85, 197, 257, 258–9, 281, 297; arrival in northern Europe, 60–4; ‘Blame not our author’ (play), 145–50; ‘book 14’ by Hypsicles, 30, 41, 44; ‘book 15’ added in fifth/sixth century, 41–2, 44; Byzantine scholarship, 40–3, 296; commentaries on, 34, 55, 126, 141, 258, 260, 279–80; commentaries on (Arabic), 55, 117, 197; commentaries on (Hebrew), 117, 120–2, 260; commentaries on (Proclus), 104–6, 115, 127, 141, 180, 242; complete Greek text, 82; and Corpus agrimensorum, 189, 191, 205; definitions, 14, 15, 105, 114, 120–2, 140, 288–9; as difficult/boring to study, 243; direct translation from Greek into Latin, 63; discussion of regular solids (books 13–15), 15, 22–3, 30, 76, 100, 220–1, 222; discussion of three-dimensional shapes (books 11–13), 15, 22–3, 100; earliest evidence for, 19–20, 22–5, 258; editions in European vernaculars, 73, 76–7, 82; editorial interventions over postulates/common notions, 115–16, 120–2, 123, 128–32; eighteenth-century new versions, 162–3; and Euclid’s other work, 179–80; and Mary Fairfax (Somerville), 241–2, 246–8; and Piero della Francesca, 217, 218, 220–1; as Great Book in liberal arts programmes, 317; Hebrew translation, 117; and later Greek geometers, 27; Latin translations of, 56, 57, 59–64, 128, 205, 206, 257; layout and structure of, 14–15, 23, 105, 114, 140, 226; and Anne Lister, 161, 165, 166–7; logical content, 128–9, 151–2, 158–9, 288–9; and medieval Latin schools, 191–2; new visibility (sixteenth-seventeenth centuries), 226–8; Newton’s copy of, 230, 231–3, 232, 234; number theory in (books 7–9), 15, 76, 108, 109, 112, 120, 183–4; oldest surviving complete copies, 46, 47, 257–8; ostraka finds, 21, 22–3, 24; papyrus fragment finds, 19–20, 23, 24; ‘parallel postulate,’ 115–16, 120–1, 122, 260–1, 263–4, 265, 266, 267–8; pons asinorum (bridge of asses), 167, 243, 273; post-Peyrard history of text, 256–9, 294–7; ‘postulates’/‘common notions’/basic assumptions, 15, 105, 114–16, 120–2, 128–9, 288–9; practical uses of, 169, 176, 177–8, 179–85, 189–92, 226–7, 237, 274, 322; printing of diagrams, 69–71, 71, 72, 127–8;
Proclus’ five-part structure of propositions, 105–6, 140–1; proposition 26 of book 6, 253; Pythagoras’ theorem in, 14, 295–6, 307, 308; ratio theory (book 10), 15, 36, 76, 183–4, 232, 233, 251; readers’ writing in, 45, 77–80, 81, 230, 232–3, 234; Bertrand Russell’s criticism of, 288–9; and Savilian professors, 82–3, 84–7; scribes’ mistakes, 41, 42, 106; and seventeenth-century thought, 151–60; six-book versions, 141; as source of wisdom/eternal truths, 83, 91, 101, 103–4, 106, 118, 142, 151–2, 158–9, 161–2; and Spinoza, 153–4; spread across Greek world, 20–1, 22, 24; survival of, 16–17, 256–9, 322–3; theorem-and-proof style, 14, 140, 152–3, 234, 236, 289; variety of printed editions, 73, 75–7, 82, 88; ways of reading, 101, 106, 237; as work of collection, 13–14


Elephantine island, 18, 22
Eliot, George (Marian Evans), 274–6; The Mill on the Floss, 269–73, 274, 275–7

For general queries contact webmaster@press.princeton.edu.
Engelfriet, Peter, 140
England: civil war of mid-seventeenth century, 83; civil wars of mid-twelfth-century, 59; Commonwealth/Protectorate, 164; popularity of Euclid in, 163–5, 242–3, 269–74, 276, 279–80, 286–9; Speidell family in, 225, 227–8, 229
Epicurean philosophers, 14
equilateral triangle, drawing of, 12, 13, 166
Eratosthenes, 28
Ernst, Max, 302, 304–5; Euclid, 300–4, 301, 305
Euclid: British imperial export of, 278, 281–4; as cultural icon, 316, 317, 318; depictions of, 2, 202, 203, 203, 207, 209, 210, 210–11; ‘Euclid debate’ in Victorian/Edwardian period, 286–90, 294–9; existence of as disputed, 304, 317; fictional accounts of, 317; geometry repurposed as art, 306–15; identifying Renaissance readers, 78–9; linking of philosophy to, 100–1, 103–6, 122, 128, 191–2; and nineteenth-century British education, 269, 271, 272, 273, 276, 277, 279–80, 286–90; as obscure historically, 8–9, 11, 304, 317; official demotion in Britain, 289–90, 296–7, 298–9, 316–17; original manuscripts as not surviving, 18; other books written by, 16, 63, 167, 179–80, 183–5, 198; Oxford University Press complete works, 87–9, 88, 162, 252, 253, 254, 255; popularity in English-speaking world, 163–5, 242–3, 269–74, 276, 279–80, 286–9; romantic legends about, 7, 8–9, 16, 95, 99, 100–1; ‘royal road’ story, 7, 8–9, 16, 27; sculpture of at Chartres, 2, 202–3, 203; veiled figure legend, 95, 100–1, 305; Data, 63, 167, 253; The Division of the Monochord, 183–5; On the Divisions of Figures (lost book), 198; Optics, 179–80, 213, 217, 219
Euclid (satellite), 316, 319–20, 321
Euclid of Megara, 95, 100–1, 305
Eudoxus of Cnidus, 13, 97
European Space Agency, 319–20
Fairfax, Mary (Mary Somerville), 241–2, 245–8, 247
Faiyum Oasis, 19–20
Farmanfarmaian, Monir Shahroudy, 312–15, 314
Fastred of Bath, 57–8
Fatimid library (Cairo), 57
Fibonacci, Liber abaci, 217
Fihrist (literary index/encyclopaedia), 194
First World War, 293
Florence, Santa Maria Novella in, 206–7
fortune-telling, 209–11
France, 116–19; Académie des Sciences, 254–5; Bourbon restoration, 255–6; École Polytechnique (Paris), 249, 250–2; education system, 273; French Revolution (1789), 250–2; Institut Poincaré (Paris), 303; Lycée Bonaparte (Paris), 249, 252, 254–5; Napoleon’s campaigns, 249, 252
Della Francesca, Piero, 214–24, 226; Flagellation of Christ, 212–13, 214–16, 220
Galen (Roman physician), 26
Galileo, 127, 131–2

For general queries contact webmaster@press.princeton.edu.
Galton, Francis, 244–5
Gandersheim, convent at (Lower Saxony), 2, 110–12, 120
Gauss, Carl Friedrich, 262, 266, 267
*Gentleman's Diary*, 164
Geometria, 206, 207, 208; in Boethius' *Arithmetic*, 205–6, 207; at Chartres, 202–3, 203, 205; in the *Mirror of Wisdom*, 208, 208–9
geometry: and actual physical space, 267–8, 288, 319; Archimedean manner, 27, 28; Aristippus on the beach, 162; ben Gershom's new treatise on, 121–2; the Bolyais' work, 267; and al-Buzjani, 196–201; circle divided into 360 parts, 29; decline in philosophical use of, 161–2; division of squares, 193, 198–9, 200; in early medieval schools and monasteries, 191–2; and Einstein's general theory, 267–8; formulas of 'spherical trigonometry,' 264–5; and Piero della Francesca, 217–24; and Greek language, 177; Greek style of mathematical writing, 11–14; Greek tradition after Euclid, 27–30; Greek tradition as performance, 11, 15, 23–4, 78, 97; identification with humanity and reason, 83, 91, 101, 103–4, 106, 118, 142, 151–2, 158–9, 161–2; Lobachevskii's work on, 263–7, 268, 319; non-Euclidean, 260, 261–8, 288, 319; as one of 'seven liberal arts,' 40, 43; John Perry's education agenda, 289–90; and *perspectiva in Renaissance*, 213–14, 216, 218–20, 223–4; and Plato, 95–100, 119, 127, 129; Proclus' metaphysics, 103–6, 119, 126, 127, 129; and the Romantic poets, 242–3, 244; sculptures at Chartres, 2, 202–3, 205; style of Spinoza, 153–4, 155, 156, 158–60, 161; theory of ratios, 15, 36, 76, 97, 183–4, 232, 233, 251; and twentieth century design, 306, 311–15 see also mathematics and geometry, practical uses of Gerard of Cremona, 63
Gerberga (Saxon abbess), 111
Germany, 66, 73–4, 273
Gershom, Rabbi Levi ben, 116, 117–22, 127, 156, 157, 158, 260
Gladstone, William, 292
Goa, 136
Göttingen Society of Sciences, 266
grammar, 40
Gray, Jeremy, 268
Great Exhibition (1851), 310
Greek world: Alexandria as Greek *polis*, 9, 10, 31, 32; Arabic preservation of learning, 51–5, 57, 166, 257, 258–9, 297; Constantinople as new centre of, 40, 57; Heath and cultural superiority, 297–9; hobbies in, 11; importance of music, 181–5; migration to Alexandria, 9; and rise of Christianity, 37; Roman period, 16, 31, 32, 37–8; spread of knowledge across, 20–1, 22, 24, 46–7; survival of Greek literature, 32–3, 51–5, 57, 166, 256–9, 297, 322–3; theoretical and practical geometry, 176–8 see also Alexandria; Athens; Byzantium 'Gregorian' calendar, 126
Gregory, David, 87–9, 162, 252, 253
Gregory, David (son), 163

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INDEX

Gregory XIII, Pope, 124–5, 126
Grieg, Samuel, 246–7
Grynäus, Simon, 73
Gutenberg, 66, 69

Hadrian, emperor, 2, 107, 108–9
Al-Hajjaj ibn Yusuf ibn Matar, 51–2,
54, 62
Halley, Edmond, 87, 162, 228
Harun al-Rashid, 49, 51, 52
Harvard, 163
Heath, Sir Thomas Little, 291–9
Hebrew, 50, 114, 116–20
Heiberg, Johan Ludvig, 257, 294–5
Henry II, King of England, 59, 60
Herculaneum, 19
Hereford and Malvern, 59, 60
Hermann of Carinthia, 63
Hermann the Lame, 210, 210, 211
Herodotus, 174
Heron August Library (Wolfenbüttel),
189
Hobbes, Thomas, 152, 156, 299
Homer, 33, 35, 256
Hooke, Robert, 82
Horace (Roman poet), 251
Hroswitha Club (New York), 113
Hroswitha of Gandersheim, 2,
107–13, 120
Hubble, Edwin, 318
Hudson, John, 87
Hume, June Amelia, 79
Hume, Sandie, 79
Hyginus (Roman surveyor), 186,
188–90
Hypatia (Theon’s daughter), 31, 37–8,
105
Hypsicles, 29–30, 41, 44
Ibn Sina (Avicenna), 55, 194
Icosahedron, 15, 23, 28, 28–30, 36,
97
Ignatius of Loyola, 124
‘imperfect’ numbers, 107–8

India: British education in, 278, 279,
281–2, 283–4; British presence,
280–4; and Heath’s work, 295;
Mughal emperors, 280; science,
mathematics and astronomy, 51,
54, 280–1
International Mathematical Olympiad,
317
Joannes of Tinemue, 63
Iran, 194, 195, 198, 313–15
Iraq, 49–51, 193–201
Isfahan, 201
Isidore of Seville, 206
Isidorus of Miletus, 42
Islamic world: design and
architecture, 198–201, 315; and
Euclid in India, 281; and Iberian
Peninsula, 116; Iranian
Revolution (1979), 313;
symbiosis between theory and
practice, 196–201 see also
caliphate
Italy, 65–8, 66, 72–3, 101, 135–6,
212–24, 254–5, 267, 273
Itard, Jean, 304
‘Jacob’s staff’ (astronomical
instrument), 118–19
Jamnitzer, Wentzel, 222, 223
Jesuit order (Society of Jesus), 123–6,
129–32, 135; in China, 135–44;
English College in Rome, 147,
148–9
Jewish culture: in Iberian Peninsula
under Islam, 116; in northern
Spain and southern France, 114,
116–19; philosophical tradition,
116–22, 156, 157, 158;
scriptures, 32; Spinoza’s writ of
anathema, 151, 153; weights and
measures in, 174
Johnson, Crockett, 306–9, 308
Josephus, 84
Judaism, 116, 118, 153
Julien Levy Gallery (Manhattan), 300
Julius Caesar, 32

Kant, Immanuel, 265
Kazan (Russian city), 260, 261–2, 266, 268
Kepler, Johannes, 127
Al-Khwarizmi, astronomical tables of, 59, 60–1, 195
Kit-Kat Club, 87
Kovalevskaya, Sofia, 275
Kronecker Wallis, 311

Ladies’ College in London, 274, 275
*Ladies’ Diary*, 164
Lagrange, Joseph-Louis, 251, 254
Latin: *Elements* translated into, 56, 57, 59–64, 128, 205, 206; Greek loan-words, 61; Hroswitha’s plays in, 111; translation movement, 57, 59–63
Legendre, Adrien-Marie, 254
Leonardo da Vinci, 222
Li Ma To (Matteo Ricci), 2, 133, 135–44, 158
liberal arts, 40, 184; artistic/sculptural depictions, 202–3, 203, 204–9, 208; Euclid as personification of geometry, 208, 209; personified as women, 207, 208–9
Lister, Anne, 2, 161, 165–7, 166, 169
Liudolf dynasty, 111
Lloyd George, David, 293
Lobachevskii, Nikolai Ivanovich, 260, 261–7, 268, 288, 319
Locke, John, 162
logic (dialectic), 40, 106, 112, 118, 142, 151–2; Aristotelian, 116, 127, 128, 152; and modern mathematics, 288; Spinoza’s *Ethics*, 156–60

Macao, 136
MacDonald, Hortense, 312
Magritte, René, 303
Maimonides (Moses ben Maimon), 116, 156
Al-Ma’mun ibn Harun al-Rashid, Abu al-Abbas, 48–9, 52–3, 54
Al-Mansur, Abu Ja’far, 49–50, 51, 55
Marcus Aurelius, *Meditations*, 46
Martianus Capella, 206
Mathematical Association, 287
*Mathematical Gazette*, 308

mathematics: abstract definitions and proofs, 267, 288; Aristotle’s view of, 127; and ben Gershom, 119–20, 127; British in nineteenth-century, 286; and al-Buzjani, 195–201; and Clavius, 129–32; clubs and magazines in Britain, 163, 164–5; concept of ‘irrationality,’ 295; and George Eliot, 274–6; and Piero della Francesca, 217–24; Greek style of mathematical writing, 11–14, 20–1, 35; Heath’s work on, 294–9; in Jesuit schools, 126; Locke on, 162; ‘mental disturbance’ trope, 241, 242, 243–5; and nature of space, 263–5, 267–8, 288, 319; Newton invents calculus, 234; philosophical status of, 119–20, 126–7, 288; *Principia mathematica* (Isaac Newton), 234–5; Proclus’ metaphysics, 103–6, 119, 126, 127, 129; readers’ writing in books, 45, 77–80, 81, 230, 232–3, 234; and Savilian professors, 82–3, 84–7; and Spinoza, 153–4; Xu and Ricci’s work in China, 139–44

see also algebra; arithmetic; geometry; mathematics and geometry, practical uses of; trigonometry
INDEX

mathematics and geometry, practical
uses of: and ‘Blame not our
author,’ 148; and al-Buzjani,
195–201; and Clavius, 127,
129–32; and Elements of
Geometry, 169, 176, 177–8,
179–85, 189–92, 226–7, 237,
274, 322; and Piero della
Francesca, 214–24, 226; and
Greek tradition, 176–8; and
music, 16, 40, 83, 112, 131,
180–5; Newtonian approach,
234–5; optics, 179–80, 213–14,
216, 218–20, 223–4, 234; and
personified arts, 207–8; and
Platonic tradition, 104, 127; John
and Euclid Speidell, 225–9; Xu
and Ricci’s work, 142–3 see also
surveying
measurement, 104, 173–6
Menaechmus (geometer), 8
Merovingian Europe, 189
Mesopotamian city states, 174
Millay, Edna St Vincent, 299
Mirror of Wisdom (fifteenth-century
manuscript), 208, 208–9
Mocenigo, Giovanni, 67, 72
Monge, Gaspard, 252
Montucla, Jean-Étienne, 251
More, Henry, 164
mosaicists, 199–201
Mosul, 201
Mueller, Ian, 289
Murray, Lindley, 283–4
Musa ibn-Shakir, 53
music, 58, 179, 204; Euclidian The
Division of the Monochord,
183–5; mathematics of, 16, 40,
83, 112, 131, 180–5
Nanjing, 135, 136, 137
Nasir al-Din al-Tusi, 85, 115, 281
National Library of Wales, 75
Navid, Haji Ostad Mohammed, 313
navigators and cartographers, 264
Netherlands, 151, 153–60
Newman, Francis, 275
Newton, Isaac, 230–5, 261, 286
Nicholas I, Tsar of Russia, 260
Nicocles of Tarentum, 179
Nicomachus (from Gerasa), 108, 109
Normans, 57, 58–9
‘Ocreatus’ (student), 62
octahedron, 15, 36, 97
Omar Khayyam, 55
open-field system of Middle Ages, 190
optics, 179–80, 213–14, 216, 218–20,
223–4, 234
Orange (French town), 114, 116,
117–18
d’Orange, Prince, 116
Orestes (Roman prefect), 37
Orphic hymns, 31, 34
D’Orville, Jacques Philippe, 46
ostracism, 21
ostraka (pot shards), 18, 21–3, 24
Otto the Great, 111, 112
Oxford University, 46–7, 81, 82–4,
86–7, 130, 163, 209
Oxford University Press, 87–9, 88,
162, 252, 253, 254, 255
Oxyrhynchus (Egyptian city), 19
Pacioli, Luca, 221–3
Paley, William, 244
papacy, 42, 116, 119, 124–5, 126
papyrus, 18–21, 22, 23, 24, 41
Paris, Matthew, 209
Pascal, Blaise, 244
‘perfect’ numbers, 2, 15, 108, 109
Perry, John, 289–90
perspective, theory of, 180, 213–14,
216, 218–20, 223–4
Petersburg Academy of Sciences, 266
Peyrard, François, 249–56, 294, 304
philosophy, Greek: Arabic
preservation of, 51, 54;
ENCOUNTERS WITH EUCLID

Epicurean, 14; linking of to Proclus, 42, 102–6, 119, 126, 127, 129, 158, 191–2; five-part structure of propositions, 105–6, 140–1; written commentary on first book of Elements, 104–6, 115, 127, 141, 180, 242;
Elements of Theology, 104, 152

Euclid, 100–1, 103–6, 122, 128, 191–2; Neoplatonism, 102–6, 127, 160, 191–2; Proclus and mathematics, 103–6, 119, 126, 127, 129; revived Platonic Academy, 102–6; Socrates, 95, 96–7, 98–9, 100, 177; source of knowledge, 96–7 see also Aristotle; Plato

physics, 104, 105, 116, 118, 120, 153; Einstein’s general theory, 267–8; Einstein’s lambda, 319

Plato, 43, 45, 46, 54, 95–6, 98; circle in Athens, 97–8; and geometry, 95–100, 119, 127, 129; legends linking to geometry, 99–100; and musical forms, 183; and theoretical mathematics, 98–9; theory of forms/ideas, 101, 119, 127, 129, 223; Meno, 96–7, 100; the Republic, 99

Proclus, 42, 102–6, 119, 126, 127, 129, 158, 191–2; five-part structure of propositions, 105–6, 140–1; written commentary on first book of Elements, 104–6, 115, 127, 141, 180, 242;
Elements of Theology, 104, 152

Pickering, William, 310 plague, 68

Queen’s College (Harley Street), 274 ‘quod erat demonstrandum,’ 12, 317

Plato, 43, 45, 46, 54, 95–6, 98; circle in Athens, 97–8; and geometry, 95–100, 119, 127, 129; legends linking to geometry, 99–100; and musical forms, 183; and theoretical mathematics, 98–9; theory of forms/ideas, 101, 119, 127, 129, 223; Meno, 96–7, 100; the Republic, 99

Ramus, Petrus, 76, 77

Ratdolt, Erhard, 65–6, 67–74, 127–8 rationalism, 158

Ratisbon, monastery of St Emmeram at, 112

Ray, Man, 303

Regiomontanus, 68


Rhetoric, 24, 40, 159, 204

Rhodes, 8

Ricci, Matteo (Li Ma To), 2, 133, 135–44, 158

Riemann, Bernhard, 267, 319

Robert of Chester, 63

Rochester, Joao da, 135

Roman empire: and Alexandria, 16, 31, 32, 37–8; collapse in the west, 39, 40; division of land, 186, 187–8; feats of engineering, 187; and surveying, 175, 186–9; three great heirs to, 48–9

Romantic poets, 242, 244

For general queries contact webmaster@press.princeton.edu.
INDEX

Rome (city), 125, 145–50, 249,
252–3; Collegio Romano, 124,
126, 131, 135; Vatican library
number 190 version, 249, 253–5,
256, 257, 294–5
Rougeux, Nicholas, 310
Rowe, Alex, 164–5
Rubensohn, Otto, 22
Ruggieri, Michele, 136
Russell, Bertrand, 288–9
Russia, 260, 261–7, 268

Saccheri, Giovanni Girolamo, 261
Saladin, 57
Samrat, Jagannatha, 281
Savile, Sir Henry, 82–3, 84
Schiaparelli, Elsa, 311–12
Schevichf, F. K., 267
science: Arabic, 57, 59, 118; and
Arabic translation movement,
52–4; Arabic vocabulary of,
53–4; Aristotelian, 33, 54, 116,
118, 120; empirical, 118–20,
155, 265; Indian, 51, 54, 280–1;
and Jesuit missionaries, 126,
139, 140; and ‘seven liberal
arts,’ 40; Somerville as ‘queen
of,’ 248; Whewell’s Mechanical
Euclid, 273 see also astronomy;
physics
Scientific Revolution, seventeenth
century, 2, 130
Scotland, 241–2, 245–6
‘Serapis,’ cult of, 10, 37
Sesostris, King, 174
Seymer, Marget, 79
Shanghai, 133–4
Shaozhou, 134–5, 136
Shibden Hall, Halifax, 165
Shiraz, Shah Cheragh shrine in, 313
Sicily, 57, 63
Simson, Robert, 279–80
Smithsonian Institution, 308–9
Socrates, 95, 96–7, 98–9, 100, 177
Somerville, Mary (Mary Fairfax),
241–2, 245–8, 247
Somerville, William, 247
Spain, 57, 59, 60, 63, 116
Speidell, Euclid, 225, 227, 228–9
Speidell, John, 227–8, 229
Spinoza, Baruch, 151, 153–5, 154;
geometric style of, 153–4, 155,
156, 158–60, 161; the Ethics,
153, 156–60
St Augustine, 126, 129
St Jerome, 129
St John’s College, Oxford, 83–4,
86–7
St Vincent, Gregory, 131
Staël, Madame de, 244
Stephanos (Byzantine scribe), 39,
43–5, 44, 77
Stoic thought, 46
stomachion (Greek game), 198
surveying: in ancient Egypt, 173–5;
and al-Buzjani, 196–7; Corpus
agrimensorum, 188–91; in Greek
Egypt, 175–6; Greek geometria
term, 177; and image of an
orderly cosmos, 192; in
Mesopotamian city states, 174,
175; in Roman empire, 175,
186–9, 190, 209; Roman groma,
186, 187, 190, 209
Sylvester, J. J., 282–3, 286
Sydney, 11
Syriac language, 50, 51, 53, 56, 62
Tartaglia, Niccolò, 72–3
Taschen (German art publisher), 310
Taurinus, Franz, 267
taxation: and Roman surveying, 188;
and surveying in Egypt, 173,
174–6
Taylor, Thomas, 242
telescopes, 125–6
Terence (dramatist), 111
tessellation, 198–201

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tetrahedron, 15, 36, 97, 220–1
Thabit ibn Qurra, 55, 62, 115
Theaetetus, 13, 97–8
theology, 104, 105, 118
Theon of Alexandria, 31, 32, 34–7, 38, 41, 42, 44, 249, 253, 257
Thierry (scholar at Chartres), 204–5, 210
Todhunter, Isaac, 280
Toledo, 57, 60, 63
Tonson, Jacob, 87
Torelli, Giuseppe, 162
Tours, 58
translation: Adelard’s linguistic stages, 56, 60, 61; Arabic science into Latin, 57, 59, 60–1; Chinese method of, 139–40; direct from Greek into Latin, 63, 128; Elements into English, 76–7, 249; first Arabic wave of, 51–2, 53–5, 257; into Hebrew from Greek and Arabic, 50, 116–17; Latin translation movement, 57, 59–64; and library at Alexandria, 32; and Peyrard, 249, 251, 254, 255, 304; two-person method, 56, 60, 139–40
Treasury, British, 292–4
trigonometry, 120, 131, 187, 195, 231, 264–5, 282, 283, 286
Trinity College, Cambridge, 230, 231–2, 234, 291–2
universities (schools): chain of new universities in northern Europe, 62; at Constantinople, 40, 42; Euclid’s dominance in English-speaking world, 163, 286–90; geometry in early medieval period, 191–2; in India, 282; mathematics in medieval period, 127; printed editions of Elements, 76; readers’ annotations in Elements, 77–8, 81, 230, 232–3, 234; in Russia, 260, 262, 266; ‘seven liberal arts,’ 40, 184, 204–9
Urbino, Duke of, 215, 220, 221–2
Urdu, 278, 279, 281, 282
Vasari, Giorgio, 222
Venice, Republic of, 65–8, 66, 72–3
Vionnet, Madeleine, 312
Vitruvius, 69, 162
Voegelin, Johannes, Elementale geometricum, 79
Wallis, John, 85, 87
weights and measures, 173–6
Westminster School, 228
Wharton, George, 299
Whewell, William, 273
Wilson, James Maurice, 245
Wisdom (play by Hroswitha of Gandersheim), 2, 107–10, 111, 112, 120
Wolf, Friedrich August, 256
Woolsthorpe (Newton’s home town), 231
Wordsworth, William, 242, 244
The World of Mathematics (collection of essays, 1956), 307
Wren, Christopher, 84, 230
writing: Arethas’ book collection, 43–6; Baghdad as centre for, 52–5; codices supplant papyrus rolls, 41; ‘continuous writing’ style, 33; Greek books salvaged at Constantinople, 40; Latin translation movement, 57, 59–64; materials used for, 18–23, 24, 41; metaphor of the corrupt text, 33, 287; ‘minuscule’ handwriting style, 42, 47; new versions of the classic texts, 31, 33, 34–7; Ptolemies’ hunger for books, 26, 27, 32; readers’ writing in books, 45, 77–80, 81, 230, 232–3, 234;
scribal copying houses, 20; Xavier, Francis, 135
scribes’ mistakes, 41, 42, 106; Xenophon, 99, 177
style of Stephanos, 43–5; text Xu Guangqi, 2, 133–5, 134, 137,
and authenticity, 33–4, 36, 139–43
256–9, 286, 287; textual criticism
at Alexandria, 33; validity of Zamberti, Bartolomeo, 128
ancient texts, 256–9, 286, 287