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(*b*. Bagnols, Gard, France, 1288; *d*. 20 April 1344),

mathematics, astronomy, physics, philosophy, commentary on the Bible and the Talmud.

Levi was also called RaLBaG (a monogram of Rabbi Levi ben Gerson) by the Jewish writers and Gersoni, Gersonides, Leo de Bannolis or Balneolis, Leo Judaeus, and Leo Hebraeus (not to be confused with Leone Ebreo [d. 1521/1535], author of the *Dialoghi d'Amore)* by Latin writers. He lived in Orange and Avignon, which were not affected by the expulsion of the Jews from France in 1306 by the order of King Philip the Fair. He seems to have maintained good relations with the papal court—the Latin translations of *De sinibus, chordis et arcubus and Tractatus instrumenti astronomie* were dedicated to Clement VI in 1342—and with eminent French and Provencal personalities: his *Luhot* and *De harmonicis numeris* were written at the request of a group of Jews and Christian noblemen and at the request of Philip of Vitry, bishop of Meaux, respectively. It has been insinuated, without foundation, that he embraced Christianity. It is possible that he practiced medicine, although the evidence is scant. He probably knew neither Arabic nor Latin and thus had to base his work on available Hebrew translations.

In 1321 or 1322 Levi finished the *Sefer ha mispar* ("Book of Number"), also called *Ma'aseh hosheb* ("Work of the Computer"; see Exodus 26:1). It deals with general principles of arithmetic and algebra and their applications to calculation: summations of series and combinatorial analysis (permutations and combinations). He used mathematical induction in his demonstrations earlier than Francesco Maurolico (1575) and Pascal (*ca*. 1654). He explained place value notation, but instead of figures, he uses Hebrew letters according to their numerical value, as well as sexagesimal fractions.

In 1342 Levi wrote *De harmonicis numeris,* of which only the Latin translation survives. Its purpose was to demonstrate that, except for the pairs 1-2, 2-3, 3-4, and 8-9, it is impossible for two numbers that follow each other to be composed of the factors 2 and 3.

Levi's trigonometrical work is in *De sinibus, chordis et arcubus* (dated 1343) based on the Hebrew text of his *Sefer Tekunah*. He uses chords, sines, versed sines, and cosines but no tangents (known in Europe since 1126). Following Ptolemaic methods, he calculated sine tables with great precision. He also formulated the sine theorem for plane triangles; this theorem had been known in the Orient since the end of the tenth century, but it is not clear whether Levi rediscovered it independently or knew it through Jābir ibn Aflah (twelfth century).

Levi wrote two geometrical works: a commentary on book I–V of Euclid's *Elements* that used the Hebrew translation by Moses ibn Tibbon (Montpellier, 1270)—an attempt to construct a geometry without axioms—and the treatise *Hibbur hokmat ha–tishboret* ("Science of Geometry"), of which only a fragment has been preserved.

The greatest work by Levi ben Gerson is philosophical in character. It is entitled *Milhamot Adonai* ("The Wars of the Lord") and is divided into six books. The fifth book deals with astronomy and is composed of three treatises, the first of which is known as *Sefer Tekunah* ("Book of Astronomy"). Completed in 1328 and revised in 1340, it was translated into Latin in the fourteenth century. It is divided

into 136 chapters and includes two works that are frequently found separately in the manuscripts: the *Luhot* (chapter 99), astronomical tables calculated for the meridian of Ezob (Izop; Orange) in 1320, and his description of the construction and use of the instrument called the Jacob's staff (chapters 4-11). Levi treated this instrument not only in the chapters mentioned (which were translated into Latin by Peter of Alexandria in 1342) but also in two Hebrew poems. In these versions it is called *keli* ("instrument") and *megalleh 'amūqqōt* ("secretum revelator"; see Job 12:22); on the other hand, one of these two poems bears the subtitle "'al ha–maqel" ("Concerning the Staff") and in it he refers to Jacob's staff (Genesis 32:10). This is the origin of the expression *baculus Jacobi,* used in some Latin manuscripts, and of the misunderstanding that he wanted to attribute his invention to someone called Jacob. The instrument is also called *baculus geometricus, baculus astronomicus,* or *balestilha*. It consists of a graduated rod and a plate that moves along the rod perpendicular to it. In order to measure an angle, the observer must look at both ends of the plate. The angle α is determined solving triangle *ABC*. This instrument helped Levi in his attempts to determine the center of vision in the eye; unfortunately the experiment was not sufficiently precise and Levi concluded that the center of vision is in the crystalline lens, thus agreeing with Galen and Ibn al–Haytham.

Levi's astronomical system began with a critique of the *Almagest* and of al–Bitrūji's Kitāb al–hay'a (translated into Hebrew in the thirteenth century). His principal sources were al–Battānī (whom he could have known through Abraham bar Hiyya), the *Islāh al–Majistī* of Jābir ibn Aflah (translated by Moses ibn Tibbon in 1274), Ibn Rushd, and Abraham ibn 'Ezra. He followed the doctrine of al–Farghānī (Hebrew translation by Jacob Anatoli, *ca*. 1231-1235) concerning the motion of the solar apogee.

He rejected the planetary systems of Ptolemy and al–Bitrūjī because he did not feel that they conformed with the data obtained by observation, as in the variations in the apparent sizes of the planets. Thus Levi observed that, according to Ptolemy, the apparent size of Mars must vary sixfold while, according to his own observations, it varies twice. The Ptolemaic epicycles also did not agree with observations (accepting the one of the moon would imply that we see both sides alternately). In the same way Levi rejected the theory of the trepidation of the equinoxes. This theoretical work was accompanied by many years of well–defined observation (1321-1339) in which Levi used his staff and the camera obscura. The use of the camera obscura in astronomy dates back to Ibn al–Haytham and was known in Europe in the second half of the thirteenth century; Levi is distinguished for his careful instructions on how the observations should be performed and for his explanation of the theoretical basis of the camera obscura.

The planetary system conceived by Levi contains a mixture of technical considerations with others of a metaphysical character. He postulates the existence of forty–eight spheres, some concentric with the earth and others not. The movement is transmitted from the innermost sphere to the outermost by means of an intermediate nonresistant fluid. The stars are affixed to the last sphere of their own system, and each sphere or system of spheres is moved by an immaterial intelligence. The number of spirits that move the heavens is, then, forty–eight or eight. Within this general framework, Levi investigated particularly the sun and the moon. His lunar model eliminated the use of epicycles; its results were practically equivalent to those of Ptolemy's model at syzygy and quadrature (where Levi believed them to be adequate enough) but an entirely new correction was introduced by him at the octants (where Ptolemaic theory could not be accepted because of systematic discrepancies with observation): there is no evidence to suggest a relationship between Levi and Tycho Brahe concerning the latter's discovery of variation (an inequality that reaches its maximum at octant). It is also clear that Levi's model represented the two first lunar inequalities better than Ptolemy's model did. Finally he eliminated practically all the variations in lunar distance from the earth, for which he rightly criticized Ptolemy's model.

The movements of the planets were less extensively dealt with (chapters 103-135). Levi carefully studied the controversial question concerning the places of Venus and Mercury with respect to the sun (chapters 129-135) without arriving at any definitive conclusion. Finally, one of his greatest contributions to medieval astronomy was his extraordinary enlargement of the Ptolemaic universe—for example, the maximum distance of Venus (Ptolemy, 1,079 earth radii; Levi, 8,971,112 earth radii); the distance of the fixed stars from the center of the earth (Ptolemy, 20,000 earth radii; Levi, $159 \times 10^{12} + 6{,}515 \times 10^{8} + 1{,}338 \times 10^{4} + 944$ earth radii); and the diameter of first–magnitude stars (Ptolemy, 4.5 + 1/20 earth radii; Levi, more than 328×10^{8} earth radii).

A few astrological treatises of Levi have been preserved, including a prediction addressed to Pope Benedict XII in 1339 and his *Prognosticon de conjunctione Saturni et Jovis (et Martis) a.D. 1345,* left unfinished at his death (the Latin translation by Peter of Alexandria and Solomon ben Gerson, Levi's brother, is extant). This conjunction of the three superior planets was also the subject of predictions by John of Murs and Firminus de Bellavalle (Firmin de Beauval). At the outbreak of the black plague of 1348 the conjunction was believed, retrospectively, to be the celestial cause that had corrupted the air.

Levi's work was influential in Europe until the eighteenth century. In the fourteenth century his astronomical tables were used by Jacob ben David Yomtob in constucting his own tables (Perpignan, 1361). It influenced the astrological work of Symon de Covino (*d*. 1367), as well as the astronomical work of Immanuel ben Jacob of Tarascon (*fl. ca*. 1340-1377). In the fifteenth century the *Sefer Tekunah* was praised by Abraham Zacuto (*ca*. 1450-1510); and the treatise *De sinibus* was the model for the *De triangulis* of Regiomontanus (1464; published 1533). The latter, as well as his disciples Bernhard Walther (1430-1504) and Martin Behaim (*d*. 1507), used the Jacob's staff, and it continued to be widely used in navigation, with various improvements, until the middle of the eighteenth century. In the seventeenth century Kepler wrote to his friend Johannes Ramus, asking him to send a copy of the *Sefer Tekunah* to him. There is also a curious cosmographical treatise written in Hebrew by an unknown Roman Jew who cites Levi as being among the greatest authors of the past.

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Julio SamsÓ