"decoupling" time at which the universe would change from being radiation-dominated to matter-dominated and hence would become transparent to radiation.

That same year, Ralph Alpher and Robert Herman predicted the existence of a cosmic background radiation as a remnant of the decoupling. Although commonly known, this calculation attracted little or no interest at the time.

See also Big Bang Cosmology; Cosmic Microwave Background Radiation; Origins of Primordial Nucleosynthesis

Descartes, René (1596–1650)

René Descartes du Perron was born at La Haye, in Touraine, on 31 March 1596. His father was a well-to-do counselor in the parliament of Rennes. From his mother he received the name du Perron and, from her property in Poitou, financial independence. In 1604, Descartes entered the Collège Royal at Flèche which had recently been founded and endowed for the Jesuits by Henry IV. His studies benefited from his uncommonly weak constitution, which furnished an excuse from the morning exercises and the chance to spend morning hours reading and meditating in bed, a custom that he retained throughout his life. The curriculum at La Flèche included logic, mathematics, and physics, as well as ethics, metaphysics, and the classics. The Jesuits were sufficiently modern to appreciate Galileo's telescopic discoveries, but Descartes's education was dominated by the Scholastic doctrine that the essential qualities of bodies or their so-called substantial forms are the causes of phenomena. Although he contributed much to the rejection of this doctrine, Descartes retained throughout his life the Scholastic conviction that genuine knowledge signifies an understanding of the underlying causes of phenomena.

Upon graduating from the University of Poitiers in law with a thesis on property rights, Descartes traveled to Paris to sample the pleasures of big-city life. He made the acquaintance of Claude Mydorge, one of the eminent mathematicians of France, and Marin Mersenne, who had studied at La Flèche as well. Mersenne's French translation of Galileo's *Mechanics* (Paris, 1634) and the role that he played in disseminating to the leading scholars of Europe the manuscript version of Descartes's most celebrated work, *Meditationes de prima philosophiae* (1641), are just two illustrations of Mersenne's devotion to the free exchange of ideas. In the years to follow, Mersenne's letters would serve as Descartes's primary link with the leading intellectuals of France.

After two years of reflection on mathematical questions, Descartes enlisted in May 1617 as a gentleman volunteer in the army of Holland and subsequently in the army of the Duke of Bavaria, as was the fashion at the time for men of his social and political station. Although nothing seems more averse to the pursuit of wisdom than the military life, Descartes's tour of duty proved to be fortuitous for his future endeavors. While serving in Breda, Descartes encountered a group of people studying a public announcement written in Flemish. He recognized the posting as a geometrical problem, and requested a translation from an individual standing next to him. The individual was Isaac Beeckman, principal of the college of Dort. Beeckman was astonished that a soldier would be interested in geometry, all the more so when Descartes handed him the correct solution to the problem the next morning. Beeckman stimulated Descartes to examine a range of problems in mechanics and acoustics and to write his first work in 1618, the *Compendium musicae* (published in 1650), which he entrusted to Beeckman's care.

Beeckman's unpublished journal testifies that he was the first person to pursue in a consistent way the idea of a mechanistic philosophy of nature (see Schuster 1977, ch. 2). He suggested that all phenomena can be explained in terms of the shape, size, configuration, and motions of insensible corpuscles of matter. The principles that govern change at the insensible level, Beeckman asserted, could be derived from the mechanical principles that govern macrophenomena. In his mature writings, Descartes would employ Beeckman's mechanical approach to nature as the basis for a physical restatement of his own considerable achievements in optics and in mathematics. For example, following his discovery of the law of refraction in 1627 or so, Descartes attempted to fashion a theory of light that would express the new macro-geometrical law in purely corpuscular terms. Many scholars before Descartes had invoked mechanical analogies to explain light, but he was the first to assert in unequivocal terms that light is nothing but a mechanical property of the luminous object and of the transmitting medium. It is for this reason that Descartes's theory is rightly regarded as the starting point of modern physical optics (see Sabra 1967, p. 48). By 1630 Descartes believed that he had developed a mechanical philosophy of nature that owed nothing to the tutelage of Beeckman. No doubt, Descartes elevated Beeckman's micro-mechanical model to a new level of sophistication by relating it to substantive results in optics, mechanics, and mathematics, but his renunciation was nurtured in part by Beeckman's subsequent attempt to claim credit for Descartes's early compendium on music.

Descartes learned of the struggle between the house of Austria and the Protestant princes, and he volunteered into the army of the Catholic Duke Maximilian of Bavaria. The winter of 1619, which he spent huddled in a heated room at Neuberg on the Danube, proved to be the critical period in his life. On November 10 of that year, Descartes reached two conclusions that figured prominently in the many controversies that would surround him during the coming years. First, he resolved that if he were to discover true knowledge, he must carry out a comprehensive reform of the sciences for himself. "A majority vote is worthless as a proof of truths that are at all difficult to discover," Descartes reasoned, "for a single man is much more likely to hit upon them than a group of people" (Descartes 1985, vol. 1, p. 119). Second, he resolved that if his reform was to be exhaustive, he must begin by systematically doubting everything that he had been taught. He retired to his bed that night "full of enthusiasm," convinced that he had discovered the foundations of "a marvelous science." He was haunted by three consecutive dreams (see Baillet, 1693, for a full account of this event). In the first, he dreamt that he was standing in a street, unable to brace a fierce whirlwind, due to a weakness in his right leg. In the second, he dreamt that he was awakened by a terrible noise like the sound of thunder. In the third, he dreamt that he was holding an open book with the passage, "Quid vitae sectabor iter?" (What way of life shall I follow?) and verses written by an unknown person and beginning "Est et non." Descartes recognized the Latin expressions as the opening lines of two poems by Decius Magnus Ausonios, a Roman poet of the fourth century A.D. He interpreted the first dream as a warning of past mistakes, the second as the descent of the spirit of truth, and the third as the opening to him of the path to true knowledge (see Williams 1967). The incident no doubt has been elaborated upon in the telling. It is instructive, however, in that it testifies to the sense of mission that infuses Descartes's writings and to his determination to work alone.

Descartes resigned his army commission for reasons that are not entirely clear, perhaps on account of atrocities that he witnessed in Hungary. He reappeared at his father's estate at Rennes in Brittany in February 1622. His father helped him to invest the proceeds from the sale of his property in Poitou. With his finances secured, Descartes resolved to see the world, and in quick succession toured Holland, France, Italy, and Switzerland, staying for some time in Rome and Venice. Scholars have speculated that Descartes's failure to visit Galileo during his stay in Italy was occasioned by jealousy of Galileo's work, but this is not likely. It is clear that Descartes had little regard for Galileo's method of exploring natural phenomena in terms of idealizations that could not be directly intuited in reality. Moreover, for Descartes the search for true knowledge always meant the search for metaphysically warranted principles that served as the foundations for explanations of natural phenomena. Indeed, Descartes's justification for explaining the entire visible world in terms of collisions between insensible corpuscles of matter was that this approach could be grounded in principles that are perfectly clear and distinct to the attentive mind. Those like Galileo and William Harvey (who simply presumed that the heart beats) would be charged with building without foundations.

Descartes returned to Paris and turned to the practical task of grinding glasses suitable for optical instruments. The central problem of geometrical optics during the first quarter of the seventeenth century was finding a simple quantitative law of refraction suitable to the study of lenses. In his *Prolegomena ad Vitellionem* of 1604, Johannes Kepler struggled mightily to establish this law but managed only the twenty-seven approximations employed in his theory of lenses, which indicated that, for small angles, the angle of refraction varies with the angle of incidence. It appears that the true law was first discovered in 1621 by the Dutch astronomer and mathematician, Willebrod Snel, some 1500 years after Cladius Ptolemy made the first concerted experimental study of refractive phenomena. Snel expressed the law of refraction as the ratio of certain lines, interpreted trigonometrically as a ratio of cosecants, whereas Descartes's *La dioptrique* (1637) would express this law in its modern form as the constant relation between the sines of the angles of incidence and refraction. Believing that Descartes had had access to Snel's manuscripts around 1632, scholars such as Isaac Vossius and Christiaan Huygens later suggested that Descartes had plagiarized from Snel the law of refraction. We now know from Descartes's correspondence that he possessed this law in 1627, long before Jacobus Golius uncovered Snel's unpublished memoir in 1632 (see Sabra 1967, pp. 100–101).

In the spring of 1629, Descartes retired to Holland where he imagined that he would have greater liberty to pursue his researches away from the bright lights of Paris. He returned to France on three occasions to settle family business and to receive pensions and honors of various kinds, and visited England once to observe some magnetic phenomena, but otherwise he remained in Holland until 1649. During this twenty-year period, Descartes changed residences some twenty-four times in order to safeguard his privacy. He corresponded extensively with the leading intellectuals of the day, such as Mersenne and Constantijn Huygens (father of Christiaan), on a wide variety of problems (notably physics, musical theory, and mathematics), but otherwise he lived a life "as solitary and withdrawn as if I were in the most remote desert" (Descartes 1985, vol. 1, p. 126). Letters were sent to Dort and transported to Descartes by Catholic priests who could be trusted to keep his location a secret.

In Holland, Descartes produced his central published writings: *Discours de la méthode*, accompanied by *La dioptrique*, and *Les météores et La géométrie* (1637); *Meditationes de prima philosophiae* (1641); *Principia philosophiae* (1644); *Notae in programma quoddam* (1648); and *Les passions de l'âme* (1649). He also performed countless experiments. Many of these were directly related to physics, but Descartes clearly was held in thrall by physiology, as evidenced by his detailed anatomical studies and his enthusiasm for performing vivisections on an assortment of animals (see Descartes 1985, vol. 1, pp. 317–18). Descartes's passion for laboratory life may seem inimical to the emphasis his method placed on reasoning from first principles. However, his writings testify to a certain contempt for reading, and throughout his life he prided himself on "seeking no knowledge other than that which can be found in myself or in the great book of the world" (Descartes 1985, vol. 1, p. 115).

Descartes was involved in recurrent controversy during his time in Holland. His *Discours de la méthode* with its companion treatises on optics, geometry, and meteorology was criticized on all sides. Pierre de Fermat, who arrived at the central idea of analytical geometry a few years after Descartes, sharply objected to the theory underlying Descartes's explanation of the law of refraction. Descartes responded by attacking Fermat's method of constructing tangents. He disputed with Giles Persone de Roberval on the curve known as the cycloid. The quadrature by Roberval was generally regarded as a remarkable achievement, but Descartes somewhat callously declared that anyone versed in geometry could have arrived at it.

Even the work on the phenomenon of the rainbow, which Descartes hoped would establish his reputation among the Jesuit scientists, failed to bring any real satisfaction. It was ignored by Marin Cureau de la Chambre, physician to Louis XIII and Louis XIV, and dismissed as unimportant by Jean Baptiste Duhamel, the secretary of the French Academy of Sciences (see Boyer 1959, ch. 8). Both scholars were steeped in traditional Aristotelian views on such matters, and so failed to discern the innovativeness of Descartes's ideas. However, two scientists who were well versed in optics, Isaac Newton and Christiaan Huygens, would subsequently suggest that Descartes's solution to the problem of the rainbow had been plagiarized.

Such allegations were not uncommon at this time. Scholars had very limited access to one another's work and were genuinely unaware of the intellectual trends that are so obvious to us in retrospect. Nevertheless, Descartes was the object of more than his fair share of contempt by his peers. One factor was his stormy and somewhat indiscreet way of responding to criticism. Another factor was his reluctance to acknowledge anything of value in the work of others, a regrettable consequence of his conviction that he was engaged in rebuilding the sciences from the ground up by himself. "It has rarely happened," Descartes proclaimed in his *Discourse*, "that an objection has been raised that I had not wholly foreseen, except when it was quite wide of the mark" (Descartes 1985, vol. 1, p. 146).

Descartes's ideas proved to be particularly disquieting in the youthful Dutch universities (cf. Ruestrow 1973). As early as 1635, Henri Renery introduced the new philosophy based on discussions with Descartes at Deventer and afterwards at Utrecht. He was succeeded in 1638 by Heinrich Regius, who pressed the Cartesian view from his chair in botany and theoretical medicine at Utrecht. François du Ban advanced Descartes's views at Leiden. In France, Mersenne distributed a manuscript copy of Descartes's *Meditationes de prima philosophiae* to an impressive galaxy of scholars, including Johannes Caterus, a theologian of Louvain; Thomas Hobbes; the Jansenist Antoine Arnauld; and Pierre Gassendi. Their objections and replies from Descartes were published, together with the *Meditations*, in 1641 in what is one of the most brilliant exchanges in the history of philosophy.

As Descartes's renown grew, so did the opposition to his ideas. Gisbert Voët, foremost among the orthodox theological professors and clergy at Utrecht, published in 1642 a pamphlet titled *Methodus novae philosophiae Renati Descartes*, which charged Descartes's teachings with fostering atheism and infidelity. Descartes was called before the magistrates at Utrecht to defend himself against these allegations of irreligion and slander, and was compelled to throw himself at the mercy of the French ambassador. These events were repeated in 1647 at Leiden, and for a time an order was passed forbidding any mention of Cartesianism. Mersenne and Mydorge died in 1648, and Descartes's isolation was thereby intensified. Claude Cherselier, a barrister at the Parlement de Paris, replaced Mersenne as his representative in Paris, and through him Descartes began to correspond with Queen Christina of Sweden. After corresponding with Queen Christina on such matters as love and the passions of the mind, it was ascertained that Descartes should travel to Sweden to take charge of the queen's education. Descartes was reluctant to leave Holland, but the invitation offered him protection from his enemies. After much hesitation, Descartes was conveyed in 1649 to Sweden by the Royal Navy.

Descartes met with the greatest reverence in his adopted land. He was even exempted from many of the observances that sovereigns expected from their retinue. However, for reasons that are not entirely clear, the queen elected to take her studies with Descartes at five in the morning. Perhaps the early regimen and the bitterness of the climate proved to be too much for Descartes, a late riser who was accustomed to ten hours of sleep each night. His constitution was never robust, and on more than one occasion, he asserted with good reason that the principal end of his studies was to conserve health (see Descartes 1985, vol. 1, p. 151). In any case, Descartes developed a lung inflammation from which he soon expired on 11 February 1650. The queen's attempt to inter him with great honor in Sweden was opposed by the French ambassador. Sixteen years after his death, his remains were conveyed to France for interment among his countrymen.

See also DESCARTES'S MECHANICAL COSMOLOGY; NEWTONIAN COSMOLOGY

[B.S.B.]

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Descartes's Mechanical Cosmology

René Descartes's celebrated assertion "je pense, donc je suis" (I think, therefore I am) is widely acknowledged as the starting point of modern philosophy. What is less often recognized is that Descartes was the first modern cosmologist; his writings, principally *Le monde, ou traité de la lumière* (1633) and the *Principia philosophiae* (1644), signify the first attempt to bring a single set of principles to bear on terrestrial and celestial phenomena. Descartes's cosmological speculations have been overshadowed by the dynamical science of motion proposed by Isaac Newton, as well as by his own lasting contributions to modern philosophy. However, Descartes was the architect of a coherent and plausible cosmology that stood at the forefront of natural philosophy for the better part of a century and played a leading role in the demise of the deeply entrenched Scholasticism. Even Voltaire, who was often a harsh critic of Descartes, conceded in his *Lettres sur les Anglais* (1728) that Descartes "was valuable even in his mistakes. He deceived himself, but then it was at least in a methodical way. He destroyed all the absurd chimeras with which youth had been infatuated for two thousand years. He taught his contemporaries how to reason, and enabled them to employ his own weapons against himself. If Descartes did not pay in good money, he however did great service in crying down that of a base alloy" (Voltaire 1910, p.115).

Descartes's cosmology is founded on the conviction that nature is a machine. The idea of a world machine was not a seventeenth-century innovation. It can be discerned, for example, in the armillary spheres with which the medieval astronomer imitated the real celestial intelligences that transported the planets through the skies. With Descartes, however, this idea received a new and powerful expression: all natural phenomena, from the motions of celestial bodies to animal and vegetative life, are explicated in terms of the geometrical property of extension and its proper modes (size, shape, position, and the disposition of parts to be moved). What distinguishes Descartes's mechanical cosmology from similar views advocated by his mentor Isaac Beeckman, the English philosopher Thomas Hobbes, and the French savant Pierre Gassendi is that it attempts to restate substantive results in optics, astronomy, and mathematics in order to forge a foundation in physical theory for the Copernican hypothesis, which Descartes accepted on account of its simplicity and clarity (see