capacity remained similar to those of Paul Broca (1824–80), anthropologists in the 20th century decided that brain size alone was an insignificant feature of race, although a major feature of human evolution.

PAE

craniometry. *See* race.

creation. *See* cosmogony; environment; evolution; fossils; microcosm/macrocosm; special creation; time (geology).

credibility. *See* enumerative induction.

criminology. *See* degeneration.

crith. *See* mole.

cross-ratio. *See* Erlangen programme.

crucial experiment. The notion of a crucial experiment appeared with Francis Bacon's (1561–1626) *Novum Organum* (1620), although Bacon actually used the term 'instantiae crucis'. His 'crucial instances', translated as 'Instances of the Fingerpost', supposedly provided *experimental tests to determine which of several possible theories about the cause of some phenomenon was correct. When approaching the fingerpost, Bacon thought, one could enumerate all possible paths (theories) available. At first all would seem reasonable, but an appropriate crucial instance would show which one fitted with the facts.

René Descartes (1596–1650) likewise expected his crucial test to indicate the one true theory. Similarly, Isaac Newton (1642–1727), discussing the 'experimentum crucis', proposed to delineate all imaginable hypotheses, rather than Bacon's demand for enumerating all possible, then testing each. Newton also expected that his crucial experiment would prove definitively one theory as true.

Investigators throughout the 19th century endorsed this idea of a crucial, definitive experimental test. In 1906, however, Pierre Duhem (1861–1916) declared in *The Aim and Structure of Physical Theory* (1906) that 'A "crucial experiment" is impossible in physics'. Because any hypothesis is embedded within a complex of assumptions and auxiliary hypotheses, Duhem contended, one can never disprove an hypothesis and cannot, therefore, prove that another is true.

Thus, crucial experiments could not prove hypotheses as true, but they might still be useful for disproving the alternatives. Accordingly, Karl Popper (*b* 1902) emphasized the crucial experiment's role in *falsifying theories. The result is not 'proof' of anything but the refutation of the worse, and hence unacceptable, theory. Imre Lakatos (1922–74) modified and developed this idea.

According to Lakatos, while no crucial experiment exists to offer 'instant rationality', i.e. definitive results, nonetheless so-called minor crucial experiments can determine which of specific competing hypotheses within a more general *research programme accord better with the data. Major crucial experiments can test the predictions of two general research programmes; the one with better results is thus rationally demonstrated to be preferable.

See also experiment.

JM

cryogenics. Cryogenics denotes the study of matter at extremely low *temperatures as well as the means of generating those temperatures. There has been a close connection between the scientific study of cold and its technological application to refrigeration. Carl Linde (1842–1934) developed a commercially practical refrigerator that used the expansion of ammonia gas in 1877. In the same year Louis Cailletet (1832–1913) liquefied air by cooling it below 180° K on the absolute temperature scale [*heat and thermodynamics]. Both Linde and Cailletet utilized the 'Joule-Thomson' effect: the gas, compressed and cooled in so far as possible, is allowed to expand rapidly from a small orifice without addition of external work. The expansion converts the *kinetic energy of individual molecules to potential energy of their separation, and consequently lowers the temperature. Raul Pictet (1846–1929) managed to liquefy oxygen (170° K) at about the same time using a cascade process wherein gases of successively lower critical temperature are used in turn to cool those remaining.

Both approaches were developed further at the turn of the century by Heike Kamerlingh Onnes (1853–1926), who, in 1906, liquefied hydrogen (20.4° K) by continuous vacuum pumping to ensure maximum expansion of the cold gas. An important breakthrough thus occurred because gases of appropriate critical temperatures do not exist to make the cascade process feasible below the temperature of liquid