Are Inventions Inevitable? A Note on Social Evolution
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ARE INVENTIONS INEVITABLE? A NOTE ON SOCIAL EVOLUTION

IT is an interesting phenomenon that many inventions have been made two or more times by different inventors, each working without knowledge of the other's research. There are a number of cases of such duplicate inventions or discoveries that are of common knowledge. It is well known, for instance, that both Newton and Leibnitz invented calculus. The theory of natural selection was developed practically identically by Wallace and by Darwin. It is claimed that both Langley and Wright invented the airplane. And we all know that the telephone was invented by Gray and by Bell. A good many such cases of duplication in discovery are part of the stock of knowledge of the general reader.

There are, however, a large number of very important instances that are not so well known. For example, the invention of decimal fractions is credited to Rudolph, Stevinus and Bürgi. Oxygen was discovered by Scheele and by Priestley in 1774. The molecular theory is due to Avagadro in 1811 and to Ampère in 1814. Both Cros and du Hauron invented color photography in 1869. The trolley car resulted from the work of Van Doeple and also Sprague, and the essential elements were devised independently by Siemens and Daft.

We think of Napier and Briggs as the inventors of logarithms, but it is not generally known that Bürgi also invented them three years previously. We associate the origin of photography with Daguerre but it was also independently invented by Talbot. Boyle's Law is known in French textbooks as Marriotte's Law. The existence of Neptune was discovered independently by Adams and Leverrier, before the planet was actually observed, the work of these two mathematical astronomers leading to its observation by others. Gauss is frequently recognized as responsible for the principle of least squares. Legendre published his account of the principle three years before Gauss did, although Gauss had used the principle still earlier.

There were four independent discoveries of sunspots, all in 1611, namely, by Galileo in Italy, Scheiner in Germany, Fabricius in Holland and Harriott in England. The law of the conservation of energy, so significant in science and philosophy, was formulated four times independently in 1847, by Joule, Thomson, Colding and Helmholz. They had been anticipated by Robert Mayer in 1842. There seem to have been at least six different inventors of the thermometer and no less than nine claimants of the invention of the telescope. Typewriting machines were invented simultaneously in England and in America by several individuals in these countries. The steamboat is claimed as the "exclusive" discovery of Fulton, Jouffroy, Rumsey, Stevens and Symmington.

That so many inventions and discoveries were made by two or more persons is not generally known. Researches into the histories of science and of inventions reveal a surprisingly large number of instances of multiple but independent origins of inventions. The appendix to this article contains a list of 148 such cases chosen from the fields of mathematics, astronomy, chemistry, physics, medicine, biology, psychology and practical mechanics. The list could be extended considerably by further research, particularly into the fields of lesser inventions. The best source for such data is the history of science within the past hundred years. The origin of the vast number of minor inventions in the practical arts is not recorded except within recent years in the files of the patent offices.

Knowledge of the origins of inventions in early times is lost. Records are largely dependent on writing, and it is only in recent years that we have written information about inventors. Among the peoples without writing there were probably many independent inventions of the same tool. But definite proof is difficult to obtain because it is not easy to tell whether the possession of the same tool by two different primitive groups is due to diffusion or to independent origin. In some cases the probability of independent origin is very great, as in the case of bronze-making in Peru and in the Old World, or the blowgun in America and in Borneo, or the pyramids in Central America and in Egypt. A fairly long list of such instances might be cited. But a statistical compilation of probable instances of multiple origins of inventions among primitive peoples would give little evidence of the relative frequency of inventions made independently, because of the vast number of cases about which we are ignorant.

But, if we leave these cases out of consideration and confine our evidence merely to the historical period, it is surprising that we can find so many cases where two or more inventors independently made the same invention, for the development of contacts has made the spread of knowledge increasingly rapid. For instance, if the knowledge of the invention of wireless telegraphy is spread quickly over all the industrialized areas, this fact in itself would cut short the researches of other inventors along similar lines. Furthermore, many inventions and discoveries are now patented, so that the invention of the same object by others either is prevented, or, if not prevented, is known. The records of the United States Patent Office show that about twice as many patents are applied for as are granted. Many of these applications are no doubt denied because the invention is already patented. This is further evidence that many inventions are made independently by more than one person.

For all these reasons a list of recurring independent inventions assumes a greater importance than would be apparent otherwise, and a list of inventions made only once would not only be of little significance but would not imply that, without the patent laws and rapid dissemination of knowledge, they would necessarily have been invented only once. In trying to form some estimate, therefore, of the frequency of inventions occurring independently more than once, one should remember these limitations on the interpretation of the data.

Bearing in mind all these considerations, the list given in the appendix to this article is very impressive. What does it mean? Several questions are raised. Are inventions inevitable? If the various inventors had died in infancy, would not the inventions have been made and would not cultural progress have gone on without much delay? Are inventions independent of mental ability? Is not the determinism in inventions a matter of cultural preparation? Is not social evolution inherent in the nature of culture?

The significance of the phenomenon of parallel occurrences of the same inventions has been ably discussed by Dr. A. L. Kroeber[1] and the answers to such questions as the foregoing have been considered by him. In general, the theory turns on two points; that is, there are two factors in the making of inventions, namely, mental ability and the existing status of culture.

Mental ability, it is thought, is related to invention in somewhat the following manner. There is little doubt that inventors are men of considerable mental ability, except, perhaps, in instances where the accidental element is large. The measurement of the mental ability of the individuals in any large sample of the general population shows a distribution resembling the familiar normal probability curve. For any particular mental trait there are only a few with large measurements and only a few with small measurements and a great many individuals in between. The distribution of mental traits is similar, for example, to the distribution of statures, in which there are few who are tall and few who are short and many with medium stature, the distribution being continuous. Inventors no doubt come from the upper portion of such a frequency distribution of ability.

Of course, we do not know just how high up in the scale of ability the inventor is found. But in a large sample the normal probability curve is such that, in the upper half of the scale of ability, will be found half the number of cases. The distribution above the upper third of the scale will usually include about one-quarter of the cases. That is to say, out of 1000 individuals about 225 on the average will be found above the upper third of the scale; and about 10 will be found above the upper tenth of the scale. Thus, even granting that the mental ability of the inventor is great, the probabilities are that out of a large sample there are many chances of finding more than

[1] A. L. Kroeber: "The Superorganic", *American Anthropologist*, New Series, Vol. 19, No. 2, April–June, 1917, pp. 163–214.

one person with a high degree of native ability. So that, if an inventor had died as an infant, there are chances that there are others with just as high native inventive ability.

But ability may vary over a period of time as well as in a cross-section of time. Thus, a random sample of 1000 individuals taken 500 years ago may have measured in inherited mental traits higher or lower in the scale than 1000 individuals chosen today. The average may be greater or less. We are here considering native or inherited ability, not the ability that results from training. Any high-school boy today knows more mathematics than did Aristotle, but his native ability in mathematics is probably much less. The way this native ability will vary over time will be by mutations or by selection. Mutations are very infrequent and the process of selection is also slow;[1] so that reckoning four generations to the century and considering the fact that a biological change or mutation must spread to a large number of individuals, there cannot be very much variation by groups in inherited mental ability over a few centuries. Therefore over the few centuries of the historical period, or at least over the period for which we can get data on the origin of inventions, the variation in native ability according to time may in all probability be neglected. There is of course —to repeat—variation within a definite sample, but the nature of the distribution of native ability is such that there is considerable probability of finding more than one individual with the particular native inventive ability. In fact such native ability may be quite plentiful.

On the other hand, the second factor in invention, the status of culture, is obviously highly variable over time, particularly in the last few centuries. The material culture three hundred years ago was very different from what it is now. It has changed rapidly. And the elements of the material culture at any one time have a good deal to do with determining the nature of the particular inventions that are made. For instance,

[1] This statement is a conclusion based upon a study of the rate of evolution and the frequency of mutations. The researches are quite extensive and the limits of this paper do not permit a development of the point.

a few discoveries regarding electricity made possible a great many inventions in which these fundamental discoveries were used or applied. The many electrical appliances could not have been invented in, let us say, the fifteenth century, because the fundamental discoveries regarding electricity had not been made. A certain cultural preparation was quite necessary for the invention of the telegraph. The fact that so many electrical inventions followed so quickly after certain researches in electricity had been made, suggests the inevitability of these inventions. And also the fact that most of the major electrical inventions were made by two or more inventors leads one to think that electrical development was more dependent on cultural preparation than on genius. Benjamin says in the introduction to his *Age of Electricity:* "It is a singular fact that probably not an electrical invention of major importance has ever been made but that the honor of its origin has been claimed by more than one person."[1] In 1745, Dean von Kleist found that by inserting an electrified wire into a phial containing spirits of wine, he could store electricity. The same experiment was made the following year by Cuneus of Leyden, and thus we have the fundamental principle of the Leyden jar. The French claim that D'Alibard was the first to discover the identity of lightning and electricity. He performed in May, 1752, the same experiment that Benjamin Franklin performed in June of the same year. The electrical effects of dissimilar metals had been noted by Sulzer in 1768 and Cotuguo in 1786, but the effective discovery was not made until 1791 when Galvani independently discovered these same results and evolved the principle of the voltaic or galvanic cell, first constructed by Volta.

The successful invention of the telegraph was the culmination of many abortive attempts to transmit electricity. The first record of any practical form of electric telegraph is described in *The Scots Magazine* in 1783 in an article supposedly written by Charles Marshal. In 1787, Lomond proposed a similar but more practical plan. The invention of the galvano-

[1] Park Benjamin: *The Age of Electricity*, p. iii.

meter by Ampère and the electro-magnet by Arago then gave a tremendous impetus and in 1831 a young American professor, Joseph Henry, constructed the first electro-magnetic telegraph. Henry did not patent his idea or make it public, and important as the invention was, it remained hidden until Morse performed his experiments in 1837 and finally put his telegraph in operation in 1844. It may be questioned whether Morse is entitled to the credit for the invention, since he neither first devised the mechanism nor originated the alphabet. There were two other inventors. Cook and Wheatstone obtained a patent in England in 1837, as a result of their joint experiments in constructing a telegraph; and just a month afterward, as a result of independent investigations, Steinheil successfully constructed a telegraph in Munich. Thus the evolution of electrical science was in the direction of the telegraph, and the invention was not dependent upon any one inventor.

Electric motors appeared simultaneously in England, France, Germany, Italy and the United States; and dal Negro, Joseph Henry, Bourbonze, McGawley and Davenport all laid claim to the invention. Given the railroad and electric motors, is not the electric railroad inevitable? At least six different men, Davidson, Jacobi, Lilly, Davenport, Page and Hall, claim to have made independently the application of electricity to the railroad. Similar inquiries show that the development of science was leading up to the following inventions, each one of which was invented by several different inventors: the induction coil, the secondary battery, the electrolysis of water, the electro-deposition of metals, the ring armature, the microphone, the self-exciting dynamo, the incandescent light and the telephone. Such a record of electrical inventions, while not negativing the factor of mental ability, certainly shows quite impressively the importance of the cultural factors.

We realize, of course, that the invention of the steamboat was dependent upon the invention of the boat and the invention of the steam engine. The dependence of an invention upon its constituent elements is a fact. The constituent elements are each in turn dependent on their constituent elements, and so on back to the ice ages and to resources of nature. But does the existence of all the constituent elements of an invention make that invention inevitable? Given the boat and the steam engine, is not the steamboat inevitable?

This tendency toward the inevitability of an invention, once given the constituent parts, and the dependence of the invention on these parts, may be seen in the history of the steam engine.[1] One sees in the interesting development of the steam engine that this invention was not dependent upon any one man and the history indicates that no one man could be expected to invent the various constituent parts as preliminary steps to making the culminating invention.

Omitting from consideration the earlier origins of the steam engine, we may start with Rivault, who proved in 1605 by experiment that water confined in a bomb-shell and heated would explode the shell. Porta had previously described an apparatus by which the pressure of steam could be made to raise a column of water. In 1615 de Caus constructed a machine similar to the one described by Porta. In 1630 Ramseye patented a "steam machine." This period was devoted largely to speculations as to the possibilities of steam and no further practical application was attempted until 1663, when Worcester constructed a machine similar to those of Porta and of de Caus, and used it to elevate water at Vauxhall. Hautefeuille in 1678 proposed the use of a piston in the steam engine and Huygens first applied this principle. Engines which were a decided improvement on Worcester's were now built. Great interest was aroused in their possibilities, and many minds set to work to solve the "problem of the steam engine". An important advance was made by Thomas Savery, who in 1698 patented a design for the first engine used in pumping water from mines. Improvements on Savery's engine were made by Desaguliers in 1718, by Blakely and Ridgeley in 1756, and also by Papin about this time. Thurston remarks that "at the beginning of the eighteenth century, every element of the modern steam engine had been separately invented and practically applied".[2]

[1] R. H. Thurston: *History of the Growth of the Steam Engine.*

[2] *Op. cit.*, p. 55.

The nature of the vacuum and the method of obtaining it were known. Steam boilers capable of sustaining any desired pressure had been made. The piston had been utilized and the safety valve invented. Thomas Newcomen constructed a new type of engine combining these elements instead of attempting an improvement on Savery's. His invention was "the engine of Huygens with its cylinder and piston as improved by Papin, still further improved by Newcomen and Calley by the addition of the method of condensation used in the Savery engine".[1] From Newcomen to Watt there were improvements in proportions and alterations of details. Watt experimented with the Newcomen engine, discovered sources of loss of heat, and set about to eliminate this waste. The Watt engine was given its distinctive form by 1785, and since that time the growth of the steam engine has not been great, the changes being in the nature of minor improvements. Contrary to popular impression, Watt, great man though he was, does not seem to have been indispensable to the perfection of the steam engine. It would be an absurdity to conclude that, even if he had died in infancy, the Industrial Revolution would not have occurred.

Our analysis and the list of multiple inventions indicates the great importance of the status of culture as a factor in the origin of inventions. While it is true that inventions are in large part culturally determined, this fact does not mean that we can at the present stage of our information predict a particular time. In some cases the probability of predicting an invention is strong as, for instance, in the case of the steamboat, which was invented by Fulton eighteen years after the perfection of the steam engine in 1785. But in most cases we do not know fully enough the cultural situation determining the invention. To say that culture is a determining factor in inventions does not tell us what are the particular cultural elements and conditions. We do not always know beforehand what the necessary constituent cultural elements are that go into the making of an invention.

But even if these elements are in existence and if there is

[1] *Op. cit.*, p. 60.

also the necessary native ability, the mental ability and the constituent cultural elements must be brought together. Inherent ability may exist but it must receive the necessary cultural training and it must be applied. The problem has to be seen, its solution socially desired and the ability must be trained and stimulated to attack the problem. This is where the idea of necessity, so commonly associated with the conception of inventiveness, comes in. Necessity will not produce an invention without the existence of the essential elements. For example, there was most urgent necessity among our forefathers not many generations ago to cure illness and prevent death. They tried magic and the use of herbs; but the science of medicine had not been developed; the cultural preparation did not exist. The need of an invention has a great deal to do with bringing ability and the cultural elements together, and is an important factor in the process, but there must exist the cultural preparation.

In conclusion, it is thought that the evidence presented of independent duplicate origins of inventions brings out forcibly the importance of the cultural factor in the production of inventions. Such data challenge us to analyze the relation of mental ability and cultural preparation as factors in the origin of inventions. To say that one of these factors is more important than the other is to condense the conclusion to unwarranted brevity. It is more satisfactory to summarize briefly the way these two factors are related. Mental ability is a factor, since no inventions could be made without it. And the mental ability of inventors is above the average. But the distribution of inherent mental ability at any one time is such that there is great probability of considerable frequency of exceptional native ability. The manifest ability necessary to produce inventions may be rare because the native ability has not been trained or applied to the problems of inventions. On the other hand, a specific invention depends upon a certain cultural preparation, and could not be made without the existence of the constituent cultural elements that make the invention.

However, if the necessary constituent elements exist, the invention may occur if there is a cultural need for it, for at any one time the distribution of inherent mental ability is such that in a large sample there are many cases of exceptional native mental ability. Witness the frequency of multiple independent inventions. Furthermore, the variation in a result, e. g., in inventions, depends on the variation of the factors. The factor of culture, since the historical period, varies rapidly within very short periods of time. The constituent elements of culture at any one time are different from what they were a few years previously. No such variation is conceivable in inherent mental ability over so short a time. In fact, it is exceedingly probable that over a few centuries there is no appreciable variation in the average or the distribution of inherited mental ability. The evidence and analysis show the tremendous importance of the cultural factor for inventions. Since the existing status of culture is so important a determinant of a succeeding culture, since culture is so highly variable, since inherited mental ability is so stable, we must conclude that the processes of cultural evolution are to be explained in cultural and social terms, that is, in terms of sociology and not in terms of biology and psychology.

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A LIST OF SOME INVENTIONS AND DISCOVERIES MADE INDEPENDENTLY BY TWO OR MORE PERSONS [1]

I

1. Solution of the problem of three bodies. By Clairaut (1747), Euler (1747) and D'Alembert (1747).

[1] The accompanying list of duplicate independent inventions is collected from histories of astronomy, mathematics, chemistry, physics, electricity, physiology, biology, psychology and practical mechanical inventions. The data are thus from the period of written records, indeed the last few centuries, and largely from histories of science. The various inventions and discoveries vary greatly in their importance. The list could be extended by further research.

There are disputes concerning many of the origins in the instances listed. Disputes frequently concern priority, a matter with which the accompanying discussion is not concerned. Where a date is doubtful a question-mark has been placed after it. Occasionally we have not been able to get the date. The most serious difficulty in making the list is the fact that the contribution of one person is in some cases more complete than that of another. For instance, Laplace's account of the nebular hypothesis is in more scientific detail than Kant's. Similarly, Halley's rôle may not have been as important as Newton's in formulating the law of inverse squares. It is sometimes doubtful just where to draw the lines defining a new contribution. Our guides have been the histories of science, and where there are differences in the historical accounts we have followed the general practice. The case of the discovery of the circulation of the blood we have excluded, as there seems to be a rather wide differ-

2. Theory of the figure of the earth. By Huygens (1690) and Newton (1680?).
3. Variability of satellites. By Bradley (1752) and Wargentin (1746).
4. Motion of light within the earth's orbit. By Delambre (1821?) and Bradley (1728).
5. Theory of planetary perturbations. By Lagrange (1808) and Laplace (1808).
6. Discovery of the planet Neptune. By Adams (1845) and Leverrier (1845).
7. Discovery of sun spots. By Galileo (1611), Fabricius (1611), Scheiner (1611) and Harriott (1611).
8. Law of inverse squares. By Newton (1666) and Halley (1684).
9. Nebular hypothesis. By Laplace (1796) and Kant (1755).
10. Effect of tidal friction on motion of the earth. By Ferrel (1853) and Delaunay (1853).
11. Correlation between variations of sun spots and disturbances on the earth. By Sabine (1852), Wolfe (1852) and Gauthier (1852).
12. Method of getting spectrum at edge of sun's disc. By Jannsen (1868) and Lockyer (1868).
13. Discovery of the inner ring of Saturn. By Bond (1850) and Dawes (1850).
14. First measurement of the parallax of a star. By Bessell (1838), Struve (1838) and Henderson (1838).
15. The effect of gravitation on movements of the ocean. By Lenz (1845?) and Carpenter (1865).
16. Certain motions of the moon. By Clairaut (1752), Euler (1752) and D'Alembert (1752).

II

17. Decimal fractions. By Stevinus (1585), Bürgi (1592), Beyer? (1603) and Rüdolff? (1530).
18. Introduction of decimal point. By Bürgi (1592), Pitiscus (1608–12), Kepler (1616) and Napier (1616–17).
19. The equation of the cycloid. By Torricelli (1644) and Roberval (1640).
20. Logarithms. By Bürgi (1620) and Napier-Briggs (1614).
21. The tangent of the cycloid. By Viviani (1660?), Descartes (1660?) and Fermat (1660?).
22. Calculus. By Newton (1671) and Leibnitz (1676).
23. The rectification of the semi-cubical parabola. By Van Heuraet (1659), Neil (1657) and Fermat (1657–9).

ence in the contributions of Cesalpino (1571) and Harvey (1776). Although our rule has been to exclude such cases of doubt, in some instances where they have been included we have placed a question mark next to the name. In several cases the independence of the research of one claimant has been questioned by another claimant or by his followers. In many cases the verdict on the controversy seems to be that each of the inventors justly deserves the distinction. Such is the case with the Newton-Leibnitz controversy over calculus, and the Torricelli-Roberval controversy on the cycloid. In the case of the microscope, telescope, thermometer, steamboat, electric railways and others, claims are still matters of dispute. In a few cases we have indicated this fact by the words "claimed by" following the subject of the discovery or invention. Most of the cases of widely different dates have special explanations as in the case of Mendel, and numerous cases where the first inventor does not publish his theory until others have come to some conclusions, e.g., there is indisputable evidence that Young discovered the principle of interference thirteen years before Fresnel, yet neglected to publish it. It has also been difficult to abbreviate the description of the discovery into a short title suitable for a list.

24. Deduction of the theorem on the hexagon. By Pascal (1639), MacLaurin (1719–20) and Bessel (1820).
25. The principle of least squares. By Gauss (1809) and Legendre (1806).
26. The geometric law of duality. By Poncelet (1838) and Gergone (1838).
27. The beginnings of synthetic projective geometry. By Chasles (1830) and Steiner (1830).
28. Geometry with an axiom contradictory to Euclid's parallel axiom. By Lobatchevsky (1836–40?), Boylais (1826–33) and Gauss? (1829).
29. Lobatchevsky's doctrine of the parallel angle. By Lobatchevsky (1840) and Saccheri (1733).
30. Method of algebraic elimination by use of determinants and by dialitic method. By Hesse (1842) and Sylvester (1840).
31. A treatment of vectors without the use of coordinate systems. By Hamilton (1843), Grassman (1843) and others (1843).
32. Principle of uniform convergence. By Stokes (1847–8) and Seidel (1847–8).
33. Logarithmic criteria for convergence of series. By Abel, De Morgan, Bertrand, Raabe, Duhamel, Bonnet, Paucker (all between 1832–51).
34. Radix method of making logarithms. By Briggs (1624), Flower (1771), Atwood (1786), Leonelli (1802) and Manning (1806).
35. Circular slide rule. By Delamain (1630) and Oughtred (1632).
36. Method of indivisibles. By Roberval (1640?) and Cavalieri (1635).
37. Researches on elliptic functions. By Abel (1826–29), Jacobi (1829) and Legendre (1811–28).
38. The double theta functions. By Gopel (1847) and Rosenhain (1847).
39. The law of quadratic reciprocity. By Gauss (1788–96), Euler (1737) and Legendre (1830).
40. The application of the potential function to mathematical theory of electricity and magnetism. By Green (1828), Thomson (1846), Chasles, Sturm and Gauss.
41. Dirichlet's principle in the theory of potentials. By Dirichlet (1848?) and Thomson (1848).
42. Contraction hypothesis. By H. A. Lorentz (1895) and Fitzgerald (1895).
43. Mathematical calculation of the size of molecules. By Loschmidt and Thompson.

III

44. Structure theory. By Butlerow (1888), Kekule (1888) and Couper (1888).
45. Law of gases. By Boyle (1662) and Marriotte (1676).
46. Discovery of oxygen. By Scheele (1774) and Priestley (1774).
47. Liquification of oxygen. By Cailletet (1877) and Pictet (1877).
48. Method of liquefying gases. By Cailletet, Pictet, Wroblowski and Olzewski (all between 1877–1884).
49. Estimation of proportion of oxygen in atmosphere. By Scheele (1778) and Cavendish (1781).
50. Beginnings of modern organic chemistry. By Boerhave (1732) and Hales (1732).
51. Isolation of nitrogen. By Rutherford (1772) and Scheele (1773).
52. That water is produced by combustion of hydrogen. By Lavoisier-Laplace (1783) and Cavendish (1784).
53. Law of chemical proportions. By Proust (1801–9) and Richter (?).

54. The periodic law: First arrangement of atoms in ascending series. By De Chancourtois (1864), Newlands (1864) and Lothar Meyer (1864). Law of periodicity. By Lothar Meyer (1869) and Mendeleeff (1869).
55. Hypothesis as to arrangement of atoms in space. By Van't Hoff (1874) and Le Bel (1874).
56. Molecular theory. By Ampère (1814) and Avagadro (1811).
57. Hydrogen acid theory. By Davy and Du Long.
58. Doctrine of chemical equivalents. By Wenzel (1777) and Richter (1792).
59. Discovery of element of phosphorus. By Brand (1669), Kunckel (1678) and Boyle (1680).
60. Discovery of boron. By Davy (1808–9) and Gay-Lussac (1808).
61. Discovery of ceria. By Hisinger (1803), Berzelius (1803–4) and Klaproth (1803–4).
62. Process for reduction of aluminum. By Hall (1886), Heroult (1887) and Cowles (1885).
63. Law of mass action of chemical forces. By Jellet (1873), Guldberg-Waage (1867), Van't Hoff (1877) and others.
64. Comparison of refractivity of equimolecular quantities by multiple function. By L. V. Lorenz (1880) and H. A. Lorentz (1880).

IV

65. Resistance of vacuum. By Torricelli-Pascal (1643–6) and von Guericke (1657).
66. Air gun. By Boyle-Hooke (prior to 1659) and von Guericke (1650).
67. Telescope. Claimed by Lippershey (1608), Della Porta (1558), Digges (1571), Johannides, Metius (1608), Drebbel, Fontana, Jansen (1608) and Galileo (1609).
68. Microscope. Claimed by Johannides, Drebbel and Galileo (1610?).
69. Acromatic lens. By Hall (1729) and Dolland (1758).
70. Principle of interference. By Young (1802) and Fresnel (1815).
71. Spectrum analysis. By Draper (1860), Angstrom (1854), Kirchoff-Bunsen (1859), Miller (1843) and Stokes (1849)
72. Photography. By Daguerre-Niepe (1839) and Talbot (1839).
73. Color photography. By Cros (1869) and Du Hauron (1869).
74. Discovery of overtones in strings. By Nobb-Pigott (1677) and Sauveur (1700-03).
75. Thermometer. Claimed by Galileo (1592–7?), Drebbel? (1608), Sanctorious (1612), Paul (1617), Fludd (1617), Van Guericke, Porta (1606), De Caus (1615).
76. Pendulum clock. Claimed by Bürgi (1575), Galileo (1582) and Huygens (1656).
77. Discovery of latent heat. By Black (1762), De Luc and Wilke.
78. Ice calorimeter. By Lavoisier, Laplace (1780) and Black-Wilke.
79. Law of expansion of gases. By Charles (1783) and Gay-Lussac (1802).
80. Continuity of gaseous and liquid states of matter. By Ramsay (1880) and Jamin (1883).
81. Kinetic theory of gases. By Clausius (1850) and Rankine (1850).
82. Law of conservation of energy. By Mayer (1843), Joule (1847), Helmholz (1847), Colding (1847) and Thomson (1847).
83. Mechanical equivalent of heat. By Mayer (1842), Carnot (1830), Seguin (1839) and Joule (1840).

84. Principle of dissipation of energy. By Carnot? (1824), Clausius (1850) and Thomson (1852).
85. Law of impact, earlier conclusions. By Galileo (1638) and Marci (1639).
86. Laws of mutual impact of bodies. By Huygens (1669), Wallis (1668) and Wren (1668).
87. Apparent concentration of cold by concave mirror. By Porta (1780-91?) and Pictet (1780–91?).
88. Circumstances by which effect of weight is determined. By Leonardo and Ubaldi.
89. Parallelogram of forces. By Newton (1687) and Varignon (1725?).
90. Principle of hydrostatics. By Archimedes and Stevinus (1608).
91. Pneumatic lever. By Hamilton (1835) and Barker (1832).
92. Osmotic pressure methods. By Van't Hoff (1886) and Guldberg (1870).
93. Law of inertia. By Galileo, Huygens and Newton (1687).
94. Machinery for verifying the law of falling bodies. By Laborde, Lippich and von Babo.
95. Center of oscillation. By Bernouilli (1712) and Taylor (1715).

V

96. Leyden jar. By von Kleist (1745) and Cuneus (1746).
97. Discovery of animal electricity. By Sultzer (1768), Cotuguo (1786) und Galvani (1791).
98. Telegraph. By Henry (1831), Morse (1837), Cooke-Wheatstone (1837) and Steinheil (1837).
99. Electric motors. Claimed by Dal Negro (1830), Henry (1831), Bourbonze and McGawley (1835).
100. Electric railroad. Claimed by Davidson, Jacobi, Lilly-Colton (1847), Davenport (1835), Page (1850) and Hall (1850–1).
101. Induction coil. By Page and Ruhmkorff.
102. Secondary battery. By Ritter and Planté (1859).
103. Electrolysis of water. By Nicholson-Carlisle (1800) and Ritter.
104. Method of converting lines engraved on copper into relief. By Jacobi (1839), Spencer (1839) and Jordan (1839).
105. Ring armature. By Pacinotti (1864) and Gramme (1860).
106. Microphone. Hughes (1878), Edison (1877–8), Berliner (1877) and Blake? (1878).
107. The phonograph. By Edison (1877), Scott? and Cros (1877).
108. Self-exciting dynamo. Claimed by Hjorth (1866–7), Varley (1866-7), Siemens (1866–7), Wheatstone (1866–7), Ladd (1866) and Wilde (1863–7).
109. Incandescent electric light. Claimed by Starr (1846) and Jobard de Clangey (1838).
110. Telephone. By Bell (1876) and Gray (1876).
111. Arrest of electro-magnetic waves. By Branley (189c–1), Lodge (1893) and Hughes (1880).
112. Electro-magnetic clocks. By Wheatstone (1845) and Bain (1845).
113. Printing telegraphs. By Wheatstone (1845) and Bain (1845).

VI

114. Theory of the infection of micro-organisms. By Fracastoro (1546) and Kircher.

115. Discovery of the thoracic duct. By Rudbeck (1651), Jolyff and Bertolinus (1653).
116. That the skull is made of modified vertebræ. By Goethe (1790) and Oken (1776).
117. Nature of the cataract. By Brisseau (1706) and Maitre-Jan (1707).
118. Operation for cure of aneurisms. By Hunter (1775) and Anil (1772).
119. Digestion as a chemical rather than a mechanical process. By Spallanzani and Hunter.
120. Function of the pancreas. By Purkinje (1836) and Pappenheim (1836).
121. Solution of the problem of respiration. By Priestley (1777), Scheele (1777), Lavoisier (1777), Spallanzani (1777) and Davy (1777).
122. Form of the liver cells. By Purkinje (1838), Heule (1838) and Dutrochet (1838).
123. Relation of micro-organisms to fermentation and putrefaction. By Latour (1837) and Schwann (1837).
124. Pepsin as the active principle of gastric juice. By Latour (1835) and Schwann (1835).
125. Prevention of putrefaction of wounds by keeping germs from surface of wound. By Lister (1867) and Guerin (1871).
126. Cellular basis of both animal and vegetable tissue. Claimed by Schwann (1839), Henle (1839?), Turpin (1839?), Dumortier (1839?), Purkinje (1839?), Muller (1839?) and Valentin (1839).
127. Invention of the laryngoscope. By Babington (1829), Liston (1737) and Garcia (1855).
128. Sulphuric ether as an anæsthetic. By Long (1842), Robinson (1846), Liston (1846), Morton (1846) and Jackson (1846).
129. That all appendages of a plant are modified leaves. By Goethe (1790) and Wolfe (1767).
130. Theory of inheritance of acquired characteristics. By E. Darwin (1794) and Lamarck (1801).
131. Theory of natural selection and variation. By C. Darwin (1858) and Wallace (1858).
132. Laws of heredity. By Mendel (1865), De Vries (1900), Correns (1900) and Tschermarck (1900).
133. Theory of mutations. By Korschinsky (1899) and De Vries (1900).
134. Theory of the emotions. By James (1884) and Lange (1887).
135. Theory of color. By Young (1801) and Helmholz.
136. Sewing machine. By Thimmonier (1830), Howe (1846) and Hunt (1840).
137. Balloon. By Montgolfier (1783), Rittenhouse-Hopkins (1783).
138. Flying machine. Claimed by Wright (1895–1901), Langley (1893–7) and others.
139. Reapers. By Hussey (1833) and McCormick (1834).
140. Doubly-flanged rail. By Stephens and Vignolet.
141. Steam boat. Claimed by Fulton (1807), Jouffroy, Rumsey, Stevens and Symmington (1802).
142. Printing. By Gutenberg (1443) and Coster (1420–23).
143. Cylinder printing press. By Koenig-Bensley (1812–13) and Napier (1830).
144. Typewriter. Claimed by Beach (1847–56), Sholes? (1872) and Wheatstone (1855–60).
145. Trolley car. By Van Doeple (1884–5), Sprague (1888), Siemens (1881) and Daft (1883).
146. Stereoscope. By Wheatstone (1839) and Elliott (1840).
147. Centrifugal pumps. By Appold (1850), Gwynne (1850) and Bessemer (1850).
148. Use of gasoline engines in automobiles. By Otto (1876), Daimler (1885) and Belden (1879?).