church, New Zealand (Mr. P. W. Glover); Voyage from Marseilles to Boston (Mr. H. D. Babcock); voyage from England to Melbourne (Miss Natalie Allen).

MEAN VALUES AND RANGE OF VARIATION.

The accompanying diagram (Fig. 1) gives the mean results in each component. It must be emphasised that though the red component, for example, is measured throughout on a consistent scale, this scale has an arbitrary difference (representing an arbitrary but constant intensity ratio to) from the scale used for either of the other components. The mean values are marked by crosses, and the extreme range in each component by the vertical lines.

The general conclusions to be drawn from this diagram appear to be as follows: First, fairly normal values can be stated for the intensity of each component at any part of the world. These values are somewhat as follows, on the various arbitrary scales:

Red	−2·5
Auroral . . .	+0·8
Blue	+6·5

The few cases which apparently lie outside these limits are believed to be due to observational causes. Full discussion is given in a paper presented to the Royal Society. The usual range of variation is from three to four fold in any given component. There is a strong correlation between the red and auroral intensities on any given occasions, and a rather less strong but still marked correlation between these and the blue. It is, however, definitely established that this correlation is not complete. A simple test for this is to match, for example, a red glass directly against a blue one by the addition of suitable neutral glasses, discarding the use of the self-luminous standard. It is found that this adjustment does not remain good for all succeeding nights, though it may be necessary to wait for some time before a marked change is observed.

ARE THE VARIATIONS AT DIFFERENT STATIONS CORRELATED?

The variations of intensity which form the subject of this investigation do not occur uniformly all over the world. They are conditioned, in large part at any rate, by local circumstances. To illustrate this, some striking illustrative cases will be given before discussing the subject by statistical methods.

Date.	Place.	Red.	Auroral.	Blue.
Jan. 16, 1926	England	−4·4	−1·4	+5·8
	Cape	−1·9	+2·0	+9·0
Mar. 2, 1926 .	England	−3·6	−0·2	+6·4
	Cape	−0·4	+2·0	+7·7
April 15, 1926	England	−3·6	−0·8	+6·4
	Cape	−2·4	+2·4	+8·3
Sept. 19, 1925	England (Northumberland)	−3·6	+1·7	+6·4
	Shetland (Lerwick)	−4·4	−2·8	+3·4
June 7, 1926 .	Hawaii	−4·7	−0·9	+5·1
	Canberra	−2·4	+2·1	+7·9

These cases have been chosen to show contrast. The mean values at the two places are in each case very nearly the same. Yet we see that occasion may be found where the intensity at one is double or more than double that at the other.

On calculating the correlation coefficients for approximately simultaneous observations at the pairs of stations mentioned, no significant coefficients were found. It will be seen immediately that there probably are long period variations which imply a correlation, but these are swamped by local irregular variations.

(*To be continued.*)

The Centenary of James B. Neilson's Invention of Hot-Blast in Iron Smelting.

By Prof. WILLIAM A. BONE, F.R.S.

IT may be considered singularly fortunate and appropriate that the forthcoming meeting of the British Association in Glasgow exactly coincides with the centenary of James Beaumont Neilson's epoch-making invention of the use of hot-blast in iron smelting, which was first conceived and demonstrated in that city. For it inaugurated a century of continuous advance in scientific fuel economy, and may be said to have done for iron-smelting what Richard Arkwright's inventions had previously done for cotton-spinning.

In 'praising famous men,' it is well to appreciate their personalities and upbringings as well as their achievements; and in many ways the case of James B. Neilson is of peculiar interest. He was born on June 22, 1792, in the village of Shettleston, near Glasgow, the son of Walter Neilson, a colliery engine-wright; his mother has been described as "a woman of capacity and an excellent housewife." After a village-school education up to the age of fourteen years, he first helped his father for a while, and afterwards became apprenticed to his elder brother John, an engineman at Oakbank, near Glasgow, who is said to have designed and constructed the first iron steamer that put to sea.

In the year 1814, Neilson took employment as a colliery engine-wright at Irvine, where a year later he married Barbara Montgomerie; in 1817 the failure of the colliery compelled them to move into Glasgow, where Neilson was appointed foreman (and five years later, manager and engineer) to the newly established gas-works, where he remained for the next thirty years.

This proved to be the turning-point in Neilson's life; for, besides ensuring him steady and congenial employment, his settlement in Glasgow brought educational opportunities of which he fully availed himself at the Andersonian College, where he studied physics and chemistry with conspicuous zeal and success. Not only did he thus improve

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his own intellectual position, but afterwards he also succeeded in inducing his work-people—mostly illiterate Highlanders and Irishmen—to follow his example; and he established an institute, with lecture-room, library, laboratory and workshop for their instruction, thus becoming a pioneer in technical education. The results of his work and inspiration were soon seen in the improvements which were introduced into gas manufacture at the Glasgow works under his direction; for, among other things, he introduced the use of fire-clay instead of cast-iron retorts in carbonising coal, and of sulphate of iron in the purification of the gas thereby produced. Undoubtedly he was a most alert and progressive gas-manager and engineer.

Neilson's crowning achievement, however, for which his name will ever stand high in the list of scientific inventors, was in connexion with iron smelting, an industry with which, until about the year 1828, he had had little or no experience; and it affords a conspicuous example of how a scientifically minded outsider may sometimes see his way along simple lines to a new great advance in a manufacturing process which those in daily contact with it have entirely missed.

In certain experiments with coal-gas, Neilson had observed how its flame luminosity could be materially increased merely by supplying it with pre-heated air through a tube surrounding the burner. This simple experiment set him thinking, and was the starting-point of all that followed. He next found that the temperature of a smith's hearth could be raised by blowing it with hot instead of cold air. To-day this may seem so obvious as scarcely to be called a 'discovery'; but to the 'practical man' of a century ago it seemed new and even surprising, so little were the thermal aspects of combustion understood, outside of a few laboratories, such as at the Royal Institution in London, where ten years earlier Humphry Davy had discovered so many new things about flame.

When Neilson first propounded to the Scottish ironmasters of his day the idea that much fuel could be economised in the smelting furnace by the simple expedient of pre-heating the ingoing blast, they pooh-poohed it. It was (they said) common experience that the furnaces made a better quality and quantity of metal in winter than in summer, which result they ascribed to lower blast temperature. Neilson, on the other hand, thought it more probably due to increased moisture in the air in summer-time, thereby anticipating to some extent the ideas about 'dry blast' put forward and proved eighty years later by James Gayley in the United States. Fortunately for the world, he was not overborne by the wisdom of the ironmasters, but persisted in his own idea until its essential truth had been triumphantly demonstrated.

Neilson's basic English patent for the invention was filed on September 11, 1828, so that the forthcoming British Association meeting will exactly coincide with its centenary; the corresponding Scottish and Irish patents date from October 1, 1828. All were entitled "Improved Application of Air to produce Heat in Fires, Forges, and Furnaces, where Bellows or other Blowing Apparatus are required," and (after referring to the generation of the blast by these known methods), the material part of the specification ran as follows:

"The blast or current of air so produced is to be passed from the bellows or blowing apparatus into an air vessel or receptacle, made sufficiently strong to endure the blast, and through and from that vessel by means of a tube, pipe, or aperture, into the fire, forge, or furnace. . . . For an ordinary smith's fire or forge, an air-vessel or receptacle capable of containing 1200 inches will be of proper dimension, and for a cupola of the usual size for cast-iron foundries, an air-vessel capable of containing 10,000 cubic inches will be of proper size. For fires, forges, and furnaces upon a greater scale, such as blast furnaces for smelting iron, and large cast-iron founder's cupolas, air-vessels of proportionately increased dimensions and number are to be employed. . . . The air-vessel may generally be conveniently heated by a fire distinct from the fire effected by the blast or current of air. . . . The manner of applying the heat to the air-vessel is, however, immaterial to the effect if it be kept at a proper temperature," the latter being described as 'considerable,' and preferably, but not necessarily, that of 'red-heat or nearly so.'

From this it is evident that what Neilson claimed was, not some particular device or apparatus, but the principle of pre-heating air in combustion as a means of economising fuel, which until then had been unthought of. In regard to iron smelting, where its greatest success was to be, it should be realised that, a century ago, the invention meant that the expenditure of a small quantity of fuel (small coal) *outside* the furnace, for the purpose of pre-heating the ingoing blast, would save many times more fuel (coke) *inside* the furnace. To-day it means even more, because the blast is now pre-heated by the combustion of part of the furnace gases, which in those days were entirely wasted.

The first trials of the invention as applied to iron smelting, which were made at the Clyde Ironworks, near Glasgow, early in 1829, were immediately successful beyond the most sanguine anticipation. For, with blast pre-heated to 300° F. only, the total coal consumption fell from 8 tons 1¼ cwt. per ton of iron with 'cold blast' to 5 tons 3¼ cwt.; and in 1833, with blast pre-heated to 615° F., it was further reduced to 2 tons 5¼ cwt. only. Indeed, it was said that, as the outcome of these experiments, the same amount of fuel produced three times as much iron, and that a given volume of blast did twice as much work, as formerly with cold blast. Actually the average furnace output had increased from 36 tons 18 cwt. per week with cold blast in 1829 to 61 tons 1 cwt. per week with blast at 615° F. in 1833. Although, as now seems probable, some part of the great economy so achieved may have been due to the simultaneous adoption of less wasteful coking methods, as well as to some concurrent reduction in the boiler coal consumption per ton of iron consequential on the greater furnace

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output resulting from the change from 'cold' to 'hot' blast, no less an authority than Sir Lowthian Bell, after an impartial survey of the facts of the case as known fifty years later, concluded that, leaving out of account the two factors referred to, the actual *direct* saving in fuel due to the introduction of hot blast by Neilson at the Clyde Ironworks between 1828 and 1833, must have amounted to *at least* 20 cwt. of coke (or say nearly $1\frac{3}{4}$ tons of coal) per ton of iron produced, a result achieved merely by imparting to the ingoing blast an amount of heat developed by the combustion of between 2 and 3 cwt. of small coal *outside* the furnace, which he characterised as being in itself "sufficiently astounding."

This was, however, by no means all; for in Scotland it was through Neilson's invention that the blackband ironstone discovered by David Mushet in 1802 first became available for iron smelting, having previously been useless for the purpose. Also, it enabled Scottish ironmasters to substitute raw coal for coke in their smelting operations. So great, indeed, were the combined advantages resulting from the invention that the Scottish output of pig-iron rose from 37,500 tons per annum in 1830 to 196,960 tons per annum in 1839, while the enhanced profits were admittedly £54,000 per annum. In South Wales the invention enabled the use for the first time of anthracite as blast-furnace fuel, the successful adoption of which in America in the year 1840 (entirely due, *as was acknowledged*, to "this simple discovery—the substitution of what is called the hot blast for the cold blast") undoubtedly founded the great Pennsylvanian iron industry, which to-day has attained to such enormous dimensions.

As time progressed, and the means of further increasing blast temperature improved, the advantages of hot blast continually increased for at least sixty years after it was first employed. Indeed, it may be said that the impetus of the pioneering work of Neilson went on until it was completed by the supplementary inventions of regenerative hot-blast stoves by E. H. Cowper and Thomas Whitwell during the years 1860–65, by which time it had revolutionised iron smelting and made possible the huge furnace outputs of the present day. It is interesting to know that Neilson was present and spoke at the meeting of Mechanical Engineers in London in 1860 when E. A. Cowper described his new regenerative stove for pre-heating the blast to 1300° F., which (as Neilson said) completed his own invention of 1828. When it is remembered that, with the exception of comparatively small amounts of 'cold-blast' iron which are still produced for special purposes, practically the whole of the world's present annual output of about 80 million tons of iron is produced in furnaces run with blast pre-heated to 1200° F. or higher, with coke consumptions ranging from about 18 to 30 cwt. per ton, according to the richness and porosity of the ore smelted, and with outputs running up to 1000 tons per furnace per diem, the enormous value of Neilson's invention to humanity can scarcely be exaggerated, and its centenary is an occasion for international celebration befitting its wide-world use and importance.

The question as to *why* the use of hot blast has effected such colossal fuel economies and furnace outputs in iron smelting during the past century has provoked much scientific research and controversy, and is perhaps even yet not fully understood, so much have we still to learn about the chemistry and thermodynamics of iron smelting. But it is scarcely too much to say that the far-reaching implications of Neilson's work were behind much of Lowthian Bell's classical investigation upon the chemical phenomena of iron smelting fifty years later, and still urge us on to further inquiries.

With the view of developing the business side of his invention, Neilson entered into partnership (in 1828) with Charles Macintosh (the inventor of 'water-proofing') and John Wilson; he needed strong support, because while the ironmasters of his day eagerly adopted his process, they did not always acknowledge his rights in it. It was said that some entered into agreements with him about it, but repudiated their obligations when the time came for paying. Be that as it may, however, in common with many other pioneers, Neilson seems to have been scurvily treated by most of those who profited largely by his inventions, and the story is a sad and unedifying one. For years he is said to have received nothing from them; indeed, an association of Scottish ironmasters was formed in 1840 for the express purpose of resisting any practical acknowledgment of the validity of Neilson's patent, thereby admitting its great technical success. Eventually, Neilson and his partners succeeded in establishing their rights after long and costly litigation against infringers, which became historic in the annals of patent law. So far as the English patent was concerned, they finally succeeded in the case of 'Neilson *v.* Hartford,' which was fought out in the Court of Exchequer in May and June 1841; but in Scotland, it was not until 1843 that the *cause célèbre* of 'Neilson *v.* Baird'—the trial of which in Edinburgh lasted nine days, and is said to have cost £40,000—finally vindicated the patent of 1828. During this action defendants admitted having made £260,000 profit by the use of hot blast, but denied the validity of the patent on grounds of verbal ambiguities; but it is satisfying to know that the Court ruled out this plea and finally decided the issue in Neilson's favour, although awarding him £11,876 only, instead of the £20,000 which he had claimed.

Neilson had joined the Institution of Civil Engineers in 1832, and in 1846 he was elected a fellow of the Royal Society. But he took fame very quietly, and in 1847 retired to a cottage which had been built in 1827 for Edmund Kean, the great tragedian, who there found it "glorious through the loop-holes of retreat to peep on such a world." In 1851 he moved to an estate which he had acquired in the Stewartry of Kirkcudbright, where he died on January 18, 1865.

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