FOUR

THE METRIC SYSTEM

Old Measures

Human beings had originally used their own bodies as a rule for linear measurement. Thus a yard was a man's good stride. An English ell (about 45 inches), was said to be related to the length of King Henry I's arm. Even in modern times a sailor, wishing to measure a rope, might still stretch out his arms, knowing that the distance between his hands would be very roughly a fathom, or six feet.

The legal measures listed in the English education code of 1900 and a part of English education for the first half of the twentieth century, set out the following units:

Length: mile, furlong, rod, pole or perch, chain, yard, foot, inch. One can hardly imagine an enormously long rod or pole of 5 1/2 yards, but the shorter unit, the chain, could be carried around to lay on the ground to make measurements. The foot as the unit of length refers of course to the foot of an adult male, whereas the origin of the inch can be better understood in its French equivalent (12 to the foot) the *pouce*, the thumb.

***Weight*:** ton, hundredweight, quarter, stone, pound, ounce, dram, grain. Here the term 'hundredweight' suggests its literal origins in one hundred 'pounds' and the homely 'stone' is only perplexing in its supposed representation of a standard weight (now 14 pounds). Less than a hundred years ago a stone could vary from 8 to 20 pounds in various parts of Britain.

***Capacity*:** coomb, bushel, peck, gallon, quart, pint. In a nineteenth-century defence of traditional measures it was argued that the bushel and the peck were well suited for men's backs, arms and hands. The pint still represents a standard measure of beer in British public houses.

***Area*:** This included 'acre', which originally represented the amount of land that a yoke of oxen could plough in a day ('acre' from the Latin *ager*, a field). Other measures related to the work output of human beings.

That so many of these units had anthropomorphic origins is hardly surprising. It would have been strange indeed if our ancestors had chosen abstract units with no relation to their daily life. One of the great problems, however, appreciated even in the Middle Ages, was the standardisation of some of these units. There were various instances when an iron rule representing a standard length was sealed into a wall so as to be accessible to the public. Thus in Paris in 1554 such a standard was available, representing the *aune*, the standard measure of drapers, corresponding roughly to the English yard. Yet in practice the *aune* differed in length for different cloths.

From the seventeenth century onwards concern was expressed in several European countries about the possibility of standardisation of weights and measures, since units of the same name were often interpreted variously in different towns. This was certainly the case in eighteenth-century France, where the variation was increasingly seen as a scandal, particularly offensive to the principles of the Enlightenment. But while people in Britain and France could urge reform, it was very difficult to imagine how this could be implemented. The French Revolution of 1789 was to provide the opportunity. Moreover, it would now be no longer a question of tidying up the old units but rather of introducing a completely new and integrated system. It should be a system simple and straightforward enough for everyone to understand. Condorcet argued that all citizens of the new republic should be self-sufficient in all calculations related to their interests. The peasant should no longer need to fear being cheated in the market place.

Early stages of reform

As early as the seventeenth century there had been ideas about a standard of measurement based on the length of a pendulum. Galileo had demonstrated that the period of swing of a pendulum for a small displacement depended entirely on its length. Several people had suggested that the length of a pendulum beating seconds could be used as a unit of length but the idea was not taken any further. Such a major change would require at the very least full government support.

In England in 1788 Sir John Riggs Miller had begun to study the problem of the diversity of weights and measures. In February 1790 he made a speech in the House of Commons proposing the choice of a general standard, from which all weights and measures might be taken. Such a standard should be derived from Nature so as to be "invariable and immutable".

Talleyrand, soon to become the French Minister of Foreign Affairs, was informed of this proposal and wrote to Miller in May 1790, expressing interest in collaboration between the two countries, to be represented by the Paris Academy of Sciences and the Royal Society of London. The Academy appointed a Commission of Weights and Measures to consider how to proceed.

If the length of a pendulum was to be chosen, the crucial question was the choice of place, since the gravitational attraction varies slightly with latitude. Talleyrand favoured a latitude of 45°, half way between the N. pole and the equator. This passed through France, and a location near Bordeaux at sea level was proposed. Miller, however, wanted London to be chosen, while Thomas Jefferson, another supporter of a universal standard based on the seconds pendulum, favoured a latitude based on the geography of the United States. Unfortunately, with the revolution in France, the political situation at the time was not favourable to international collaboration and in March 1791 the Academy of Sciences announced that it intended to proceed unilaterally.

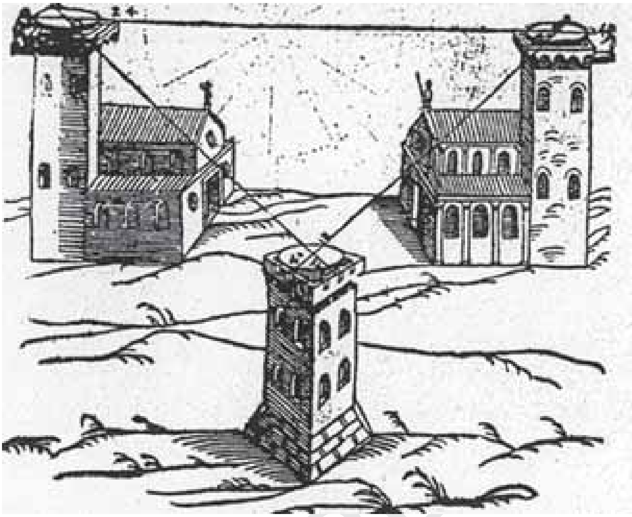
Meanwhile the Academy Commission had decided against the seconds pendulum, since the unit of time, the second, depended on astronomical factors and was not obviously a natural and unchanging unit. It decided instead to adopt as the natural unit of length a measurement based on the size of the Earth. This unit, the metre, should be one ten-millionth part of the distance from the N. pole to the equator, drawn along a convenient meridian. Several previous geodesic measurements along the Paris meridian were available but it was thought that even greater accuracy could be attained if new measurements were taken over some 10 degrees of latitude, stretching from Dunkirk in the north to Barcelona in the south, both being at sea level. The ten-millionth fraction was chosen because it came very near to the length of the Paris *aune* (roughly three feet).

The Academy was encouraged by the fact that Earth measurement in France had a long history. The French were in an ideal position to think in terms of Earth measurement since, earlier in the eighteenth century, French scientists had led the world in triangulation procedures (see below) to construct splendid maps of France. Also it already had relevant data based on the Paris meridian. The Academy's proposal was accepted by the National Assembly on 26 March 1791. Britain was to follow the French example in map making when the Ordnance Survey was established also in 1791.

The Commission of Weights and Measures

The Commission was divided into several committees to work out different aspects of the new system. With the optimistic assumption that appropriate measurements could be carried out within a year, a generous budget was agreed. The most onerous task was the measurement of the meridian, which depended on triangulation measurements. These involved the establishment of a series of measured base lines and the very accurate reading of angles within a series of imaginary triangles formed by prominent features of the landscape. The astronomer Jean-Baptiste Delambre was to be responsible for the northern part of the Paris meridian, while his colleague Pierre Méchain was to survey the south.

After the collapse of central authority, civic control had passed to the towns and there was great suspicion of strangers, not only there but also in the surrounding countryside. The surveyors, therefore, had to furnish themselves with passports and full accreditation if they were to travel freely. Indeed political mistrust was to be almost as great an obstacle to the survey as bad weather. In a flat countryside church steeples provided excellent



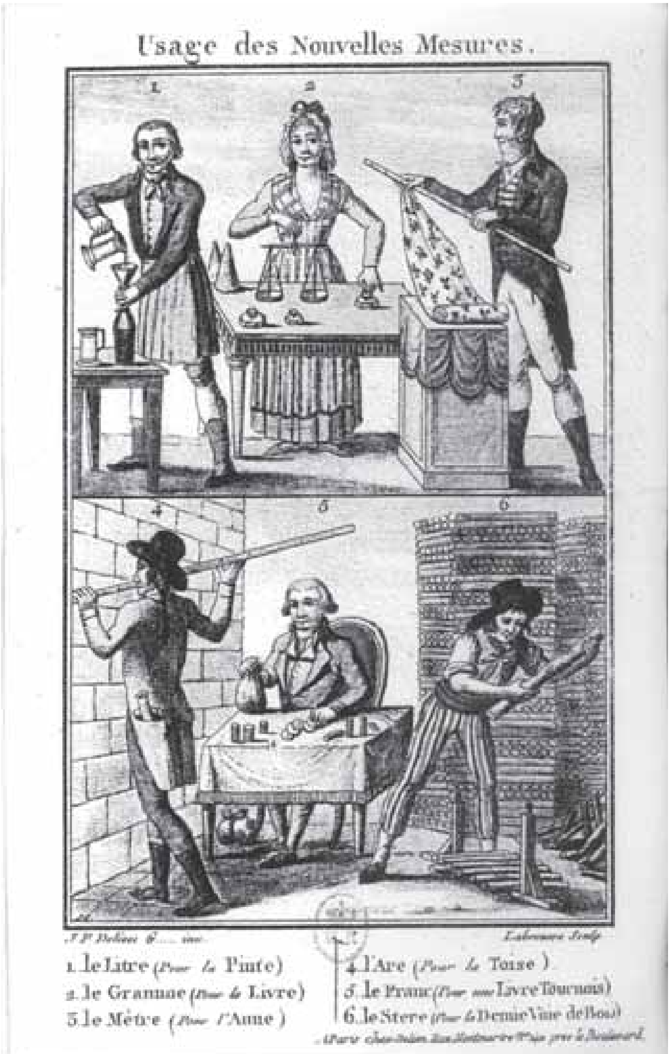
Simple triangulation illustrated (16th century)

survey stations. Otherwise the scientists had to rig up their own observation towers.

The survey was to take many years and the morale of the survey teams was not improved by the news in August 1793 that the government had decided to go ahead with the metric system based on the provisional metre, using existing data. In other words it might seem that their work was not strictly necessary. Another message told Delambre of the suppression of the Academy, which further lowered his morale. Then in January 1794 he received a letter from the Commission of Weights and Measures, telling him that he had been purged from the Meridian Survey for political reasons, together with several colleagues including Lavoisier. He was instructed to hand in all his readings. Altogether political interference kept Delambre away from his survey for 18 months.

During all this time his colleague Méchain had more difficult territory to survey in the south. Free movement on the Spanish side of the Pyrenees in time of war was very difficult. Communication with Paris was constantly interrupted. Not only did he have to deal with mountain terrain but he found himself dangerously near to battles fought between the French and Spanish armies. He was arrested in Barcelona and was not able to resume his measurements until the summer of 1795. The greatest trial suffered by the scrupulous Méchain came in March 1794, when he discovered a discrepancy in his measurements, a problem he tried to conceal.

Meanwhile, back in Paris, the other members of the Commission were hard at work. Lavoisier and Haüy were to determine the new unit of weight, later called the gram. Special copper vessels were made by the famous instrument maker, Fortin. With the greatest possible accuracy the scientists measured the weight of a cubic decimetre of rainwater at the temperature of melting ice. These experiments were almost completed when Lavoisier, unpopular as a taxation officer, was arrested and executed in May 1794, a tremendous loss to science. He was never to appreciate that water was a curiously abnormal liquid with a maximum density at 4^{o}C (more accurately 3.98^{o}C.). This was only discovered after his death when Lefèvre-Gineau carried out a number of experiments with water at different temperatures. He



Contemporary illustration, showing the replacement of traditional measures by metric units.

was thus able to redefine the gram as the weight of a cubic centimetre of distilled water at its temperature of maximum density, rather than O^{o}C.

Lavoisier had been a central figure in the Commission, as both secretary and treasurer and responsible, for example, for supplying funds to the two astronomical teams (far away from Paris), who were measuring the meridian. It was Lavoisier who reported on the progress of the work of the Commission to its political masters. It was also he who assembled some thirty skilled workers to assist in the metric project. He had to argue that they should be exempt from conscription. By 1793 he had, with difficulty, to justify to the new political assembly, the Convention, the many sophisticated measurements necessary to produce a comprehensive and unchallengeable new system of weights and measures.

There had to be one central permanent standard. The first standard metre was made of copper but, for the definitive metre, newly-discovered platinum was chosen, partly because it would not corrode. Although, on heating, its expansion was minimal, a clever device was introduced to measure even the very slight increase in length in hot weather. Platinum, however, was very difficult to work because of its high melting point. In 1792 Lavoisier constructed several porcelain ovens, fed by oxygen, in order to reach the highest possible temperature. He was successful in producing the platinum required for several standard measures.