Notes from the Oesper Collections

The Steelyard Balance

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Most variations on traditional balance design can be understood using the famous "lever law" (1):

$$m_l d_l = m_r d_r \quad [1]$$

first formulated by the Greek mathematician Archimedes in the 3rd century BC, where m_l is the mass of the object on the left side of the fulcrum or pivot, d_l is its distance from the fulcrum, m_r is the mass of the object on the right side of the fulcrum, and d_r is its distance from the fulcrum.

In the oldest form of the balance – the double pan suspension balance (figure 1) – the pans were hung beneath the beam and placed equal distance from the fulcrum, this distance being kept constant. A series of weights were then added to the right-hand pan until they balanced the object or objects in the left-hand pan that were being weighed, at which point:

$$m_l = (d_r/d_l)m_r \text{ or } m_l = m_r \quad [2]$$

by virtue of the fact that:

$$d_l = d_r \quad [3]$$

Since balancing was usually achieved by adding up the combination of discrete weights in the right-hand pan, such balances are said, in modern parlance, to be "digital" in nature.

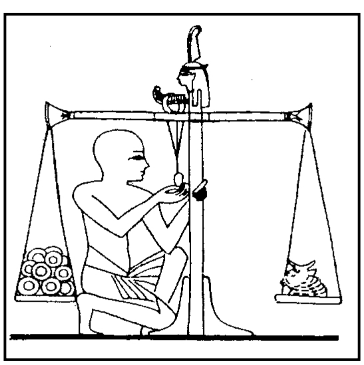


Figure 1. An Egyptian double-pan suspension balance, circa 1400 BC.

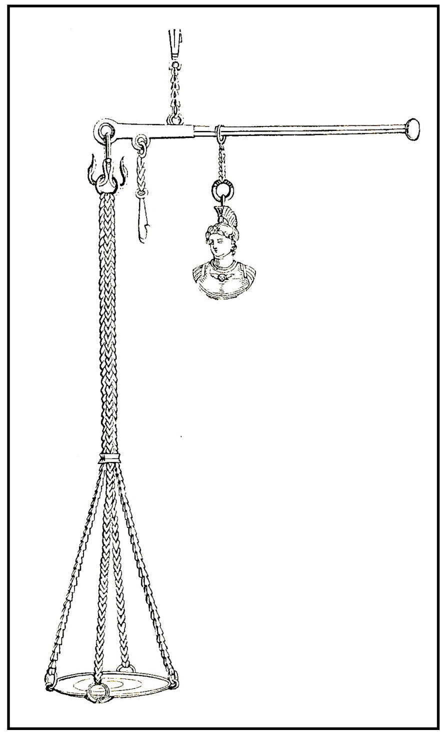


Figure 2. Drawing of a 1st century AD Roman steelyard found at Pompeii.

In the case of single-pan balances based on the steelyard principle (figure 2), the distance of the left-hand pan from the fulcrum remains fixed as in the case of the double-pan balance. However, there is no right-hand pan. Rather a constant weight, known as a rider or counterpoise, is moved along the beam to the right of the fulcrum until balance is achieved and the mass of the object being weighed is then determined by the equilibrium distance of this weight from the fulcrum using graduation marks on the beam itself. Thus:

$$m_l = (m_r)/d_l)d_r \text{ or } m_l = kd_r \quad [2]$$

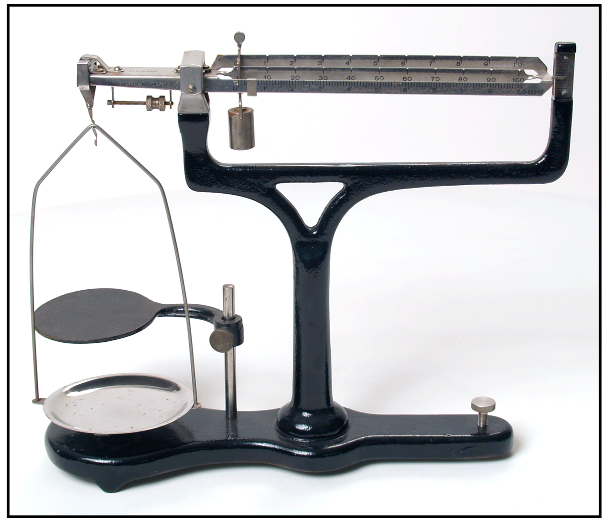
by virtue of the fact that m_r *and* d_l are both kept constant. Since use of a set of discrete weights that must be totaled has been eliminated, such balances are said, in modern parlance, to be "analog" in nature (2).

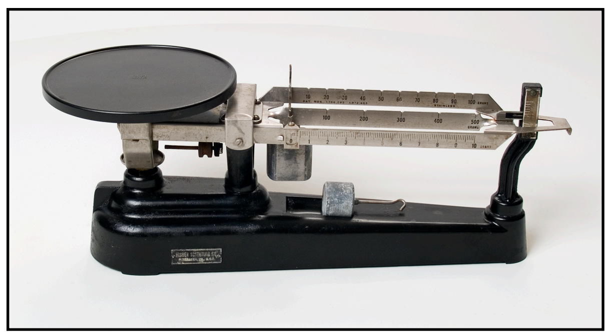
Figure 3. A recently acquired 19th-century Chinese steelyard or so-called "opium balance" with an 11" ivory beam and accompanying "fish-shaped" storage case (Jensen-Thomas Apparatus Collection).

The steelyard principle was discovered, apparently independently, by both the Romans (figure 2) and the Chinese (figure 3) sometime around 200 BC, though some historians claim that it was used by Greek engineers as early as the 5th century BC, which is to say, several hundred years before Archimedes explicitly formulated the lever law (3).

Steelyards come in all sizes, from those used in traditional Chinese pharmacies and in chemical laboratories to commercial versions used to weigh sides of beef (figure 4), or even, in the case of platform versions, human beings, cars, and trucks. Around the last decade of the 19th century a modification known as a triple-beam balance was introduced into chemistry for use in student laboratories (figures 5 and 6). In keeping with the name, the beam was split into three parallel segments, each with its own characteristic sliding weight – one for hundredths of grams, one for grams, and one for tens of grams (4).

Figure 4. A medium-size late 19th-century commercial steelyard with a 18.5" beam (Jensen-Thomas Apparatus Collection).





Figures 5 and 6. Examples of circa 1940 triple-beam laboratory balances based on the steelyard principle. *Top*: A triple-beam balance with a traditional suspended pan sold by Welsh Scientific. *Bottom:* A triple-beam platform balance sold by Fisher Scientific with the pan mounted on top of, rather than suspended below, the beam (Jensen-Thomas Apparatus Collection).

In Roman times the steelyard was known as a *statera* and during the Renaissance as a *romana* or *Roman balance*. As for the current name *steelyard*, it has been suggested that this is derived from the widespread use of these balances by the trading base of this name established by the Hanseatic League in London during the 14th century.

References and Notes

1. The lever law is often expressed using weight rather than mass but, in sharp contrast to scales, in all balances both the left and right sides are subjected to the same degree of gravitational acceleration. Thus:

$w_l d_l = w_r d_r$ or $(m_l gh)d_l = (m_r gh)d_r$ or $m_l d_l = m_r d_r$

by virtue of the fact that value of *gh* is the same on both sides of the balance and thus cancels.

2. Yet a third variation on the use of the lever law in balance design was a primitive device known as a *bismar*. This had a pan for the unknown on the left, a fixed weight on the right, and a fulcrum that could be slid along the beam until balance was achieved. The mass of the unknown was then determined from the equilibrium position of the fulcrum using markings on the beam. Hence:

$m_l = (m_r)(d_l/d_r)$ or $m_l = k(d_l/d_r)$

by virtue of the fact that m_r is constant. Like the steelyard, this was an analog balance.

3. B. Kish, *Scales and Weights: An Historical Outline*, Yale University Press: New Haven, CT, 1965, pp. 56-66, 74-77. This author attributes the invention of the steelyard to the Romans alone. For the early history of the steelyard in China, see J. Needham, *Science and Civilization in China*, Vol. 4, Cambridge University Press: Cambridge, 1962, pp. 24-27.

4. A variation on the triple-beam balance was the so-called "Chaslyn Balance," which kept a single beam but used three separate movable weights or riders. See C. E. Linbarger, "On a Balance for Use in Courses in Elementary Chemistry," *J. Am. Chem. Soc*., **1899**, *21*, 31-33.