Chapter 2 Edward Williams Morley
Physical Chemist

1869 - 1906

Morley's background

Fig. 2-1. E. W. Morley

In 1869, the 30 year old Edward Williams Morley, from Williams College in Massachusetts, was appointed professor of chemistry and "natural history". The young Morley is pictured in **Fig. 2-1.** He had graduated from Williams in 1860. He then completed three years of theological studies at the Andover Theological Seminary, followed by a few months as a medical assistant serving the army in the civil war and a three year stint teaching in a private school. In 1868, he took a position as pastor of a church in Twinsburg, Ohio. His talents as a scientist were soon recognized by the administrators of the nearby Western Reserve College, and he was quickly offered a faculty position. He did not return to the ministry, though he did his share of preaching in the local church.

Morley would spend his entire scientific career on the Western Reserve faculty, until his retirement in 1906. While he ultimately held the position as chairman of the Chemistry Department, he must also be counted among the *physicists* of the institution. As pointed out by C.H. Cramer in his history of CWRU, of the 52 major papers published by Morley, 23 were in pure physics. His chief research concerned precision measurements of the atomic masses of oxygen and hydrogen (published in 1895). Of course, the ether-drift experiment which Morley performed in 1887 with A. A. Michelson was 100% physics. Michelson's successor, Dayton C. Miller, said, "The physicists have always felt that they had a strong claim on Prof. Morley as one of their group."

Between 1868 and 1882, Morley was Mr. Science in Hudson, and indeed in all northeast Ohio. His interests were wide-ranging. He set up the first teaching laboratory at the college; he was a pioneer in offering hands-on chemistry experience to the students. For fifteen years he commuted by train to Cleveland to teach chemistry at the Cleveland Medical School; he acted as scientific consultant for industrial firms and the civil courts.

Ratio of oxygen and hydrogen atomic masses

Morley's experiments to measure atomic masses were spread over many years, from the 1870's in Hudson into the 1890's at the new Cleveland campus. He worked very much alone, designing ever more refined techniques. Like his colleagues, Michelson and Miller, Morley was more concerned with making precise measurements than with the underlying "theory".

The ratio of the various atomic masses to the mass of the hydrogen atom was a controversial subject in the latter half of the 19th century. It was widely believed, as proposed by William Prout in 1815, that each element should have an atomic mass exactly equal to an integral number times the hydrogen mass. As measurements became more precise, that simple picture became less viable, and Morley was determined to settle the issue beyond any doubt. Ultimately, with the publication of his results in 1895, Morley was able to quote an oxygen to hydrogen mass ratio of 15.879 with an uncertainty in the last decimal place, a ratio clearly different from 16.000. ("On the Densities of Oxygen and Hydrogen and the Ratio of their Atomic Weights", *Smithsonian Institution Contribution to Knowledge* 980, 1895. Much of this material is expertly described in the doctoral dissertation of Ralph R. Hamerla (PhD, History of Science, CWRU May 2000. I had the pleasure of serving on Dr. Hamerla's committee.) Morley's result was not understood until the discovery of the neutron and Einstein's theory on the equivalence of mass and energy quantified the role of binding energy in nuclear masses.

Method 1: T P V & M

How, then, does one go about determining M_O/M_H? In one set of experiments, Morley measured the densities of each gas. He expressed his results in terms of the ratio of the two densities measured at 0^o C and 760 mm Hg pressure. (The assumption is that each gas is ideal, so that the ratio of densities equals the ratio of the atomic masses.) The trick, then, is to determine the absolute temperature and pressure, the volume of the gas and its mass, and its purity, all to a precision of one part in 10,000. Morley used rather large volumes of gas, typically 10 to 20 liters in a glass globe. Much of his work was done in the basement of Adelbert Hall which today houses the top CWRU administrators. **Fig. 2-2**, which shows Morley's barometers with their telescope readouts, comes from the 1895 Smithsonian Institution report.

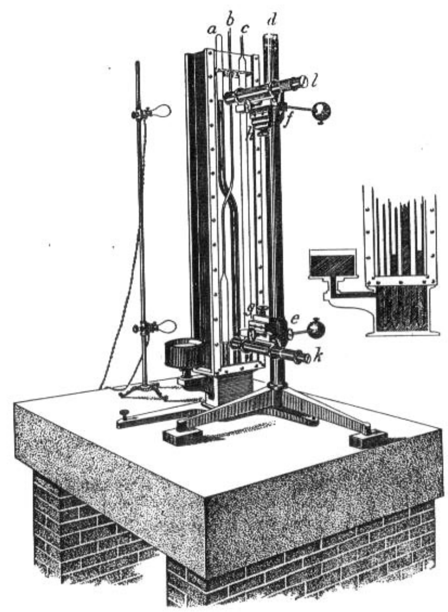

Fig. 2-2. Precision barometers.

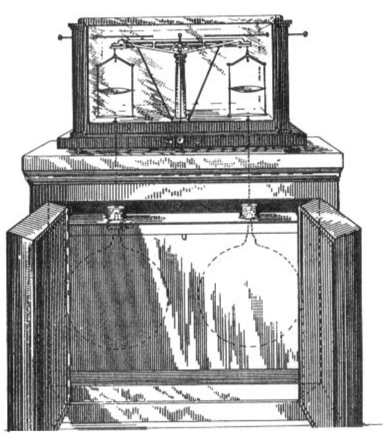

Fig. 2-3. Gas globes suspended from balance.

It is interesting to step through part of such a measurement, noting all the minute corrections he made along the way. For example, here are the steps he followed to determine the internal volume of the glass globe. Evacuate the globe and weigh it in air by suspending it below one of the pans of a precision balance. **Fig. 2-3** shows Morley's drawing of the weighing spheres and balance. The balance (one microgram sensitivity up to a loading of 1.2 kg) was constructed by

Rüprecht of Vienna and loaned to Morley by the Smithsonian. Next, following the example of Archimedes, submerge the evacuated globe in water at known temperature, adding weights to a pan which hangs in the water below the globe. Determine how much weight is required just to submerge it. This gives the mass of the water displaced, and thus the external volume of the globe. Then fill the submerged globe with water and weigh it in water again to determine the buoyant force on the glass itself. This, along with the known density of the glass, gives the volume of glass. The difference between the exterior volume of the globe and the volume associated with the glass walls gives the interior volume of the globe.

Note that one never has to weigh the large mass of water which fits in the globe; this would be far beyond the capacity of the balance. The brass weights used to sink the globe were typically about one kilogram each, so they could be weighed one at a time. Morley weighed them (and the pan) in water to remove the effect of the buoyant force on the weights themselves. Morley even determined the effect of the hydrostatic pressure on the volume of the globe, which contracted slightly when the globe was evacuated. To illustrate the quantities he was measuring, the precision of his measurements, and the careful corrections he applied, I give a typical set of numbers taken from his 1895 publication: This is a measurement of the interior volume of a 10 liter glass globe.

	grams
total weight of brass weights added to pan to submerge globe	8425.64
reduction to vacuum *	-1.17
reduction to temperature **	-0.11
corrected weight of brass	8424.36
weight of cage and pan	178.32
weight of evacuated globe	1015.22
sum of weights suspended from left balance pan	9617.90
balancing weights on right pan	351.09
weight of water displaced	9266.81

	cubic cm
divide by density of water at 17.24 C ρ = 0.998765 g/cc to find volume of water displaced	9278.27
contraction of globe to 0 C	-4.47
exterior volume of glass globe at 0 C	9273.80
repeat above measurements with globe filled with water	
resulting volume occupied by glass after similar small corrections	443.07
subtract to get interior volume of globe	8830.73

* correct for buoyancy in air

** correct for thermal contraction when weighing in water

The globe is then filled with purified hydrogen or oxygen gas and similar measurements are made to determine the mass of the known volume of gas, thus determining their densities. Morley gives detailed descriptions of his calibration of thermometers and barometers. In the latter case, since the barometric pressure is determined by the height of the mercury column and by the value of g, the acceleration due to gravity, he introduces a factor of 0.999627 to correct g to an altitude of 216.1 m above sea level at New York and a latitude of 41^o 30’ 15”. (Do not conclude that this represents a correction of four parts in 10,000 in the gas densities. The absolute pressure is used only indirectly to do some small corrections. The weights of the precisely measured brass masses *do* depend on the local value of g, but when they are used with a balance, the correction is the same on both sides and thus cancels out.) Morley’s expertise in the techniques of chemistry was essential to the production of pure gasses and the removal of contaminants.

Method 2: V & M

The set of measurements of the type outlined above was only a beginning for Morley, who continued to seek ways to reduce the uncertainties. For example, the precision of the measured densities depends linearly on his ability to measure temperature and pressure and to extrapolate his results to zero Celsius and one atmosphere. Morley completely redesigned his apparatus so that the hydrogen and oxygen densities could both be measured at the *same* temperature (13.5 C) and the *same* pressure (736.49 mm Hg). Furthermore he devised a way to manipulate the globes and weights without ever touching them. This included an arrangement which allowed him to reverse the loads from one balance pan to the other to correct for imperfections in the balance itself. The possibility of loss of gas through leaky stopcocks was avoided by use of fusible metal plugs.

Method 3: M_H M_O & M_{water}

The third type and ultimate set of measurements of the atomic mass ratio was done with an apparatus in which measured masses of hydrogen were burned with measured masses of oxygen to produce measured masses of water. The apparatus is illustrated in **Fig. 2-4**. The gasses were combined in a container and ignited by high voltage electrodes. To quote Hamerla: “Morley conducted 12 experiments using 42 liters of hydrogen and 21 liters of oxygen which produced 34 grams of water in each experiment.” Here are the numbers, in grams, from one of the runs: Hydrogen taken 3.8392; hydrogen residue 0.0010; hy-

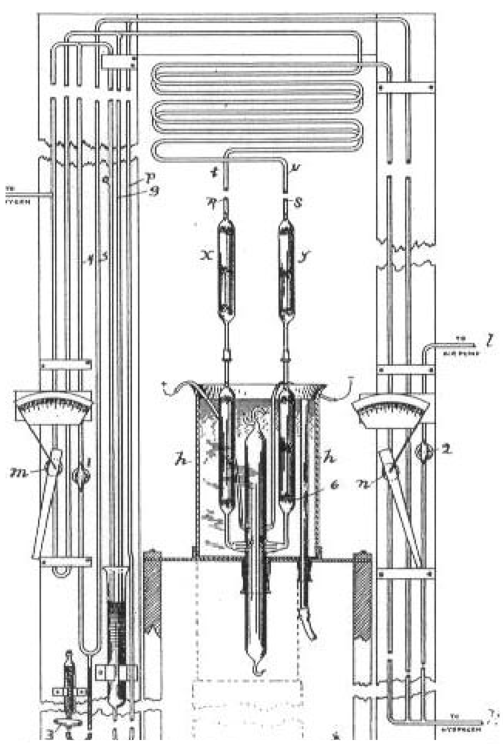

Fig. 2-4. Weighing H, O and H_2O.

drogen used 3.8382; oxygen taken 30.4741; oxygen residue 0.0041; oxygen used 30.4700; O/H atomic mass ratio 15.877; water formed 34.3151. (This latter value differs by only 0.007 grams from the sum of O used and H used.)

The density ratio from this water-synthesis method as published by Morley is 15.879 ± 0.00032 and may be compared to the currently accepted value (from a table in Krane's 1988 book on nuclear physics). This is 15.8731 (when one includes the contributions of naturally occurring hydrogen and oxygen isotopes). The Morley value differs from the current value by about 4 parts in 10,000, so that the published uncertainty was a bit optimistic.

The most remarkable fact about this long series of experiments is that Morley found the **identical** result in all the different methods employed: the early density measurements, the isothermal, isobaric measurements of isolated systems, and the water-synthesis measurements. Morley was nominated for the Nobel Prize in 1902, and according to C. H. Cramer, "stood second in the voting" (though I thought these votes are usually secret).

It has been suggested that if Morley had been able to continue and further refine these measurements, he might very well have discovered deuterium, *the isotope of hydrogen which makes up about one part in 10,000 in terrestrial hydrogen, or the isotope* ^{18}O *which is two parts per thousand in oxygen gas. It is not clear to me how such discoveries could follow from Morley's measurements since there were no theoretical predictions for the masses with which to compare. These discoveries had to await magnetic or mechanical separation of the isotopes.*

Beyond atomic masses: with Michelson and Miller

In the world of physics, Morley's name is usually associated with that of Michelson. Morley had been at Western Reserve since 1868. In 1882 Reserve moved from Hudson up to Cleveland to be a neighbor of the new Case School. Morley and Michelson got together when the latter arrived in Cleveland in 1883. Michelson was 31 years old, Morley 45. Their famous 1887 ether-drift experiment, and Morley's role in it, will be described in the next chapter. In a second, less well-known collaboration, Morley worked with Michelson's successor, Dayton Miller, in a continuation of the ether-drift experiment. More on this work in Chapter 4.

Well respected for his uniquely skillful experimental work, Morley was elected president of the AAAS (American Association for the Advancement of Science) in 1895. A biography of Morley was published in 1957. *"Edward Williams Morley: his influence on science in America"* by Howard R. Williams, Chemical Education Publishing Co., Easton, Pa.

Morley's relationship with the college administration, in the person of President Charles Thwing, deteriorated when, in 1896, after a year's leave of absence spent in Europe, Morley returned to Cleveland to find his laboratory and equipment cruelly disassembled. It would seem that Dr. Thwing was not appreciative of Morley's world-renowned work or, perhaps, of academic research in general. By 1906, when Morley was 68, he found it impossible to remain at Western Reserve, and he resigned with a one-sentence letter, returning to the east, sadly following the lead of his five young physicist predecessors. He lived in West Hartford until his death in 1923. His ample estate was bequeathed to Williams College. President Thwing is memorialized today in the name of Charlie's Place pizza and sandwich shop in the student union.