03. Inventing Temperature: Chap 3.

1. Extending the Temperature Scale Beyond the Freezing Point of Mercury.

- 1733-43. Johann Gmelin in Siberia.

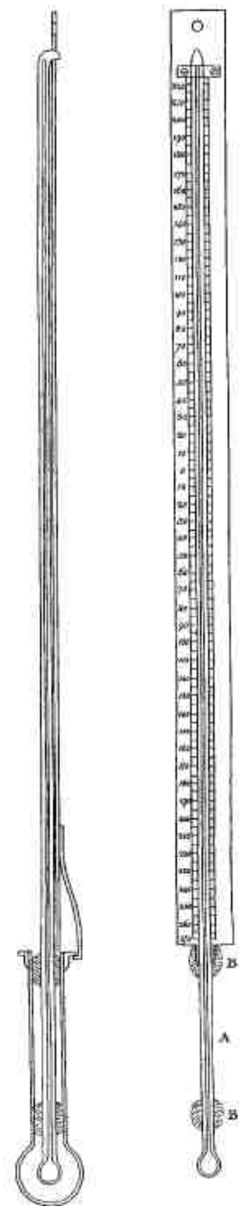
"The air seemed as if it were frozen, with the appearance of a fog, which did not suffer the smoke to ascend as it issued from the chimnies. Birds fell down out of the air as if dead, and froze immediately, unless they were brought into a warm room. Whenever the door was opened, a fog suddenly formed round it. During the day, short as it was, parhelia and haloes round the sun were frequently seen, and in the night mock moons and haloes about the moon."

Johann Gmelin
(1709-1755)

"Our thermometer, not subject to the same deception as the senses, left us no doubt of the excessive cold; for the quicksilver in it was reducted to $-120°$ of Fahrenheit's scale."

- *But*: Low readings were actually due to frozen mercury in thermometer!

- 1759-60. Joseph Adam Braun in St. Petersburg.
  - Observes frozen mercury in "freezing mixture" of nitric acid and snow.
- 1772. De Luc: argues in favor of mercury thermometers.
  - *Claim 1*: Mercury experiences linear contraction down to freezing point.
  - *Claim 2*: Alchohol does not.
- 1781-82. Thomas Hutchins in Fort Albany.
  - Mercury thermometer in cylinder filled with mercury.
  - Mercury outside thermometer freezes before mercury inside thermometer.
  - *Result*: Freezing point of mercury −40°F (−40°C).
- *But*: What about supercooling effects?
- *And:* Does mercury really contract linearly?



- 1837. Claude Pouillet.
  - *Thermocouple* = measures temperature by measuring electric current across the heated junction of two metals.
  - Establishes comparability between bismuth-copper thermocouple and air thermometer (using paste of dry ice mixed with sulphuric acid).
  - Thermocouple indicates mercury freezes at $-40.5°C$ ($-40.9°F$).
  - Six different alcohol thermometers give readings within $0.5°C$ of $-40.5°C$.

Claude Pouillet
(1790-1868)

> "What he had established was quite an impressive consistent ring of measurement methods: the expansion of air, the intensity of current in the bismuth-copper thermocouple, and the expansion of alcohol all seemed to be proportional to each other in the range between the freezing point of water and the temperature of [the] paste." (Chang, pg. 118.)

2. Extending the Temperature Scale Beyond the Boiling Point of Mercury.

Josiah Wedgwood's 1782 pyrometric scale.

- Burning-shrinkage:

> "In considering this subject attentively, another property of argillaceous [claylike] bodies occurred to me; a property which...may be deemed a distinguishing character of this order of earths: I mean, the diminution of their bulk by fire....I have found, that this diminution begins to take place in a low red-heat; and that it proceeds regularly, as the heat increases, till the clay becomes vitrified [takes a glassy form]"

Josiah Wedgwood
(1730-1795)

- Final sizes of clay pieces were (apparently) only a function of temperature.

> "It now only remains, that the language of this new thermometer be understood, and that it may be known what the heats meant by its degrees really are."

- *Task*: Connect Wedgewood scale with mercury-based Fahrenheit scale.

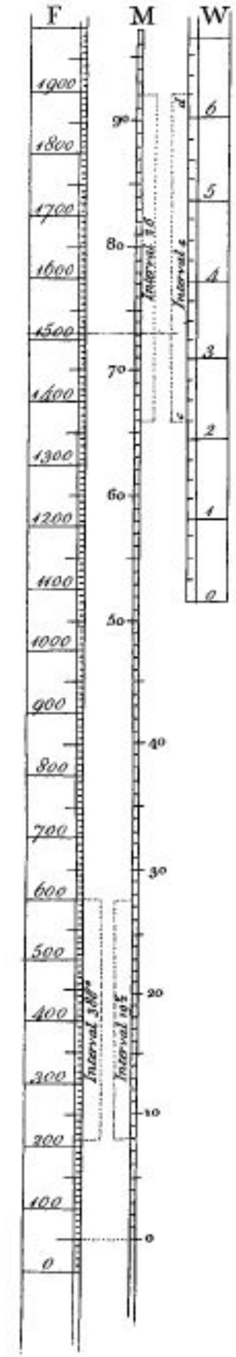
- Wedgwood's silver patch:
  - *Low-end of silver scale overlaps mercury scale.*
  - *High-end of silver scale overlaps Wedgwood scale.*
  - *<u>Result</u>: 1 Wedgwood degree = 130 Fahrenheit degrees.*

<u>*Problems:*</u>

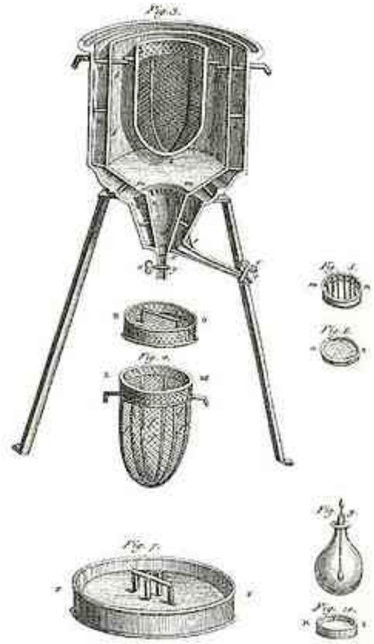
1. Difficulty in reproducing Wedgwood's clay pieces.
2. Skepticism over the Wedgwood-Fahrenheit conversion:
   (a) *Estimate of temperature of red heat too high.*
   (b) *Estimate of Fahrenheit to Wedgwood conversion too high.*
   (c) *No reason to believe contraction of clay is linear with temp.*

> *<u>But</u>*: "How can we be sure that Wedgwood was wrong? And, more pertinently, how can we be sure at all that any of the proposed alternatives to Wedgwood pyrometry were any better?" (Chang, pg. 127.)

> *<u>Claim (pg. 128)</u>*: "Each of the temperature standards favored by Wedgwood's critics was as poorly established as Wedgwood's own. Their main strength was in their agreement with each other."



Alternative Pyrometric Standards



Lavoisier and Laplace's ice calorimeter (1782)

- Expansion of Platinum.
  - *Problem*: Is expansion linear?
- Ice or Water Calorimetry.
  - Initial temp of hot object determined from amount of ice melted, or amount of temp rise produced in cold water.
  - *Problem*: Assumes specific heat of hot object is constant.
- Time of Cooling.
  - *Problem*: Is law of cooling of the given object linear?
- Air Pyrometry: use air thermometer.
  - *Problems*: No conclusive argument for air thermometers until Regnault in 1840s.
  - *And*: Regnault did not establish that air expanded linearly with temp.
  - *And*: Regnault's comparability tests were only for relatively low temps (~340°C).
  - *And*: How to make air thermometers robust at high temps?
    - 1836: James Prinsep's air thermometer made from gold.
    - 1836. Pouillet's air thermometer made from single piece of platinum.

	Clay °W	Conv to °F	Mercury	Metal	Ice	Water	Air	Cooling	Current values
Melting point of tin			481, 415	441, 442			383, 410		449
Melting point of bismuth			537, 494	462, 476			662, 493, 518		521
Melting point of lead			631, 595	609, 612			617, 500, 630		621
Melting point of zinc	3	705		699, 680, 648, 773			932, 680, 793		787
Red heat visible in the dark				947, 977				743	
Melting of antimony	7	955		809, 810			847, 810	942	1167
Red heat visible in daylight	0	1077		1050, 517		1272	977, 1200	1036	
Melting point of brass	21, 21	3807, 1836		1869					1706-1913
Melting point of silver	28, 22	4717, 1893		1000, 1893, 2233, 1873, 1682			1000, 1832, 1830		1763, 1761, 1763
Melting point of copper	27, 27, 27	4587, 2205	1450, 2313, 2548, 1996			2295			1984, 1981, 1984
Melting point of gold	32, 32, 32	5237, 2518		1301, 2518, 2590, 2016, 1815			2192, 2282		1948, 1945, 1948
Welding heat of iron, least	90, 95	12777, 6504							1922
Welding heat of iron, greatest	95, 100	13427, 6821							2192
Red hot iron	88	12485			2732				
White hot iron	100	14055			3283				
Melting point of cast iron	130, 130	17977, 8696		1601, 3479, 2786	3164		1922-2192		2100-2190
Melting point of soft iron	174,175	23665, 11455			3988	3902	2700-2900		
Melting point of steel	160, 154						~2370-~2550		
Greatest heat, air furnace	160, 170	21877							
Melting point of platinum				over 3280					3215

(Chang, pp. 130-132)

3. Operationalism.

- 1927. Percy Bridgman: Physical limitations force us to use different operations in measuring the same concept in different realms of phenomena.

<u>*Example*</u>: Length.

- Measured with ruler for medium-sized slowly moving objects.
- Measured by amount of time light takes to travel for astronomical lengths.
- Measured in terms of light-years for even larger distances.

Percy Bridgman
(1882-1961)

"To say that a certain star is 10^5 light years distant is actually and conceptually an entirely different kind of thing from saying that a certain goal post is 100 meters distant... If we have more than one set of operations, we have more than one concept, and strictly there should be a separate name to correspond to each different set of operations."

"Our concepts do not automatically extend beyond the domain in which they were originally defined... The Bridgman ideal is always to back up concepts with operational definitions, that is, to ensure that every concept is independently measurable in every circumstance under which it is used." (Chang, pp. 145, 147.)

Bridgman's Reductive Doctrine of Meaning:

"In general, we mean by any concept nothing more than a set of operations; the concept is synonymous with the corresponding set of operations... If a specific question has meaning, it must be possible to find operations by which an answer may be given to it."

- *Problem*: Why is there continuity of meaning even in the absence of continuity of measurement operations? Why are extensions of concepts sought in the first place?

Example: Wedgwood's temperature scale.

- Why was he compelled to provide an extension that connected his scale to Fahrenheit's?
- *Suggests*: "...there was a real and widespread sense that a property existed in the pyrometric range that was continuous in its meaning with temperature in the everyday range.... [This sense] rests on very basic qualitative causal assumptions about temperature..."
- *Moral*: "...concepts can and do get extended to fresh new domains in which experiences are scant and observations imprecise, even if no definite measurement operations have been worked out." (Chang, pg. 150.)

3 Types of extention

1. *Semantic extension* = extension of the meaning of a concept to a new domain.
2. *Operational extension* = semantic extension by means of specifying a set of operations that are required to hold in order for the concept to have the desired meaning.
3. *Metrological extension* = operational extension by means of a method of measurement.

"The justification of a metrological extension arises as a meaningful question only if some other aspects of semantic extension (operational or not) are already present in the new domain in question." (Chang, pg. 150.)

The Use Doctrine of Meaning

- The meaning of a concept is determined by the way it is used.
- *Thus*: The method of measurement is only one particular aspect of a concept's meaning.

4. Strategies for Metrological Extension.

Two Criteria for metrologically extending a concept:

1. *Conformity*: If the concept possesses any pre-existing meaning in the new domain, the new standard should conform to that meaning.
2. *Overlap*: If the original standard and the new standard have an overlapping domain of application, they should yield measurement results that are consistent with each other.

(a) Disconnected Extension.

- *Wedgwood's initial scale prior to the Fahrenheit conversion.*

(b) The Wedgwood Patch.

- *Intermediate silver scale satisfies both conformity and overlap.*
- *But: Did silver expand at the same rates as mercury and clay pieces in the relevant domains of overlap?*

Wedgwood's scale "...was only as good as a bridge made of three twisted planks held together with a few nails here and there." (Chang, pg. 153.)

(c) Whole-Range Standard.

- *Singe standard to cover the entire range.*
- *Alcohol for cold domain (poor overlap with air & mercury); Platinum (but even it melts...).*

(d) Leapfrogging.

- *Establish a law in normal domain, and then extrapolate it into new domain.*
- *Metallic pyrometers. Law of thermal expansion at low temp extrapolated to high temps.*

(e) Theoretical Unification.

- *Establish a theoretical framework that justifies each proposed measurement standard.*

5. Mutual Grounding.

- *Recall*: Wedgwood's scale was rejected in favor of other scales that agreed among themselves but were not necessarily more reliable than Wedgwood's.
- *Circular justification*? Platinum scale is good because it agrees with ice calorimeter scale, which is good because it agrees with platinum scale...

Coherentism: "...what I have in mind at this point is the use of coherence as a guide for a dynamic process of concept formation and knowledge building, rather than strict justification." (Chang, pg. 155.)

"We are like sailors who have to rebuild their ship on the open sea, without ever being able to dismantle it in dry-dock and reconstruct it from the best components."

Otto Neurath
(1882-1945)

- Wedgwood's scale as a single plank versus alternative scales as a bunch of planks that at least fit together...