02. Inventing Temperature: Chap 2.

1. The Problem of Nomic Measurement.

- Thermometers filled with different liquids did not agree.

Mercury	Alcohol	Water
0 (°C)	0	0
25	22	5
50	44	26
75	70	57
100	100	100

(Chang, pg. 58.)

Attitudes:

(a) Each type of thermometer defines a separate standard of temperature (*operationalism*).

(b) Any given instrument can be chosen as the standard (*simple-minded conventionalism*).

(c) The instrument that defines a standard that makes the laws of thermal physics the simplest should be chosen (*sophisticated conventionalism*).

(d) Temperature is an objective property that really exists. Only one thermometer can be correct in measuring its true values (*realism*).

- A realist faces the "Problem of Nomic Measurement"...

The Problem of Nomic Measurement:

1. We want to measure quantity X.
2. Quantity X is not directly observable, so we infer it from a directly observable quantity Y.
3. This requires a law that expresses X as a funciton of Y: $X = f(Y)$.
4. The form of f cannot be discovered or tested empirically because that would involve knowing the values of both Y and X.

- Three contenders for the claim of indicating true temperatures:
  - atmospheric air
  - mercury ("quicksilver")
  - ethyl alcohol ("spirit").

2. The Method of Mixtures.

> "Mix equal amounts of freezing water (at 0°C centigrade by definition) and boiling water (at 100°C, again by definition) in an insulated vessel; if a thermometer inserted in that mixture reads 50°C, it indicates the real temperature." (Chang, pg. 61.)

De Luc's (1772) Inquiries on the Modifications of the Atmosphere.

	Degree of real heat (calculated)	Reading of the mercury thermometer	Condensation of mercury between last two points
Boiling water	$z + 80$	80.0	--
	$z + 75$	74.7	5.3
	$z + 70$	69.4	5.3
	$z + 65$	64.2	5.2
	$z + 55$	53.8	5.2
	$z + 50$	48.7	5.1
	$z + 45$	43.6	5.1
	$z + 40$	38.6	5.0
	$z + 35$	33.6	5.0
	$z + 30$	28.7	4.9
	$z + 25$	23.8	4.9
	$z + 20$	18.9	4.9
	$z + 15$	14.1	4.8
	$z + 10$	9.3	4.8
	$z + 5$	4.6	4.7
Melting ice	z	0.0	4.6

(Chang, pg. 63.)

Real degree of heat (calculated)	40.0
Mercury thermometer	38.6
Olive oil thermometer	37.8
Camomile oil thermometer	37.2
Thyme oil thermometer	37.0
Saturated salt water thermometer	34.9
Spirit thermometer	33.7
Water thermometer	19.2

(Chang, pg. 64.)

- *Big Assumption*: In previous table, De Luc assumes that it takes the same amount of heat to raise the temperature of a given amount of water by each 5° increment.
- *More generally*: The *specific heat* of water is assumed to be constant and does not depend on temperature.
  - *Specific heat = amount of heat required to raise the temperature of an object by one unit.*

Is this assumption right?

3. Caloric Theories of Heat.

- *Core Claim*: A material substance ("caloric") is either the cause of heat, or heat itself.

Irvinist Caloric Theories (William Irvine 1743-1787)

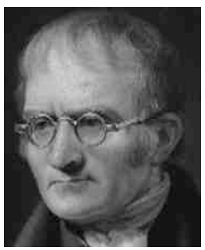
$$(\textit{amount of caloric}) = (\textit{heat capacity}) \times (\textit{absolute temperature})$$

- *Heat capacity* = capacity to store caloric.
  - *Identical to specific heat.*
- *Absolute temperature* = quantitative measure of amount of caloric (zero for total absence of caloric).
- *Consequence*: If the amount of caloric remains constant in a body, but its heat capacity increases, its temperature must go down.
  - *Thus*: Specific heat depends on temperature (*contra* De Luc)!
- *Latent heat* = heat required to keep temperature constant when heat capacity is increased.

- *If bucket widens (capacity increases), level of liquid descreases (temperature).*
- *Must add liquid (latent heat) to keep level constant.*

Dalton's (1808) New System of Chemical Philosophy.

- Mixing of hot and cold water results in a *decrease* in volume.
- A decrease in volume entails a decrease in heat capacity, and thus an increase in temperature.
- *Thus*: *Mixtures must have higher temperatures than those given by De Luc.*



John Dalton
(1755-1844)

"Till this point is settled [constancy of specific heat], it is of little use to mix water of 32° and 212° [in Fahrenheit's scale], with a view to obtain the true mean temperature."

Chemical Caloric Theories (Antoine-Laurent Lavoisier 1743-1794)

- Two types (states) of caloric:
  - *Combined (or latent) caloric* = caloric that is chemically combined with particles of matter causing fluidity; *does not affect temperature.*
  - *Free (or sensible) caloric* = caloric that is not chemically combined with matter particles; *affects temperature.*
- *Thus*: Heat capacity (capacity for caloric) is not identical to specific heat (caloric necessary to raise temperature by one unit).

René-Just Haüy
(1743-1822)

Haüy's (1803) Elementary Treatise on Natural Philosophy

- When a body expands under heating,
  - *expansion is due to combined/latent caloric;*
  - *temperature increase is due to free/sensible caloric.*
- *And*: At lower temperatures, more combined caloric is needed.
  - *At lower temperatures, less distance between molecules and thus greater attraction; thus less free caloric is present.*
- *Thus:* *Mixtures must have lower temperatures than those given by De Luc.*

The Privileged Status of Gases in Caloric Theories

- *Assumption*: Intermolecular attractive forces in gases are weak.
- *Gay-Lussac (1802)/Dalton (1802)*: All gases expand by an equal fraction of the initial volume when temperature is increased by the same amount.
- *Suggests*: Gases expand uniformly with temperature.
  - *So*: *Air thermometers provide accurate measures of temperature.*

> *But*: "Even if we grant that the thermal expansion of gases is a phenomenon determined exclusively by the effect of temperature, it still does not follow that the volume of a gas should be a linear function of temperature. Not all functions of one variable are linear!" (Chang, pg. 69.)

Laplace's (1821) Argument for the Superiority of Air Thermometers

Pierre-Simon Laplace (1749-1827)

- *Assumptions*:
  - *Combined/latent caloric* = caloric bound in molecules. ← does not exert repulsive force
  - *Free/sensible caloric* = caloric bound in molecules. ← exerts repulsive force
  - *Free caloric of space* = caloric disengaged from matter.
  - *Temperature* = density of free caloric of space.

- *Claim 1*: The pressure of a gas is given by $P = K_1\rho^2 c^2$.

> ○ K_1 = constant; ρ = density of gas; c = amount of free caloric in each molecule.
>
> ○ P is proportional to the repulsive force between any two molecules, which is proportional to c^2, and to the pressure exerted by a molecular layer of density ρ on a layer of the same density, which is proportional to ρ^2.

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  - *Temperature* = density of free caloric of space.

- *Claim 1*: The pressure of a gas is given by $P = K_1 \rho^2 c^2$.

- *Claim 2*: The temperature of a gas is given by $T = K_2 \rho c^2$.

  - ○ K_2 = constant.
  - ○ Density of free caloric of space, T, is proportional to amount of caloric emitted/absorbed by each molecule, which is proportional to the density of caloric present, ρc, and to the amount of free caloric in each molecule for removal, c.

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- *Claim 1*: The pressure of a gas is given by $P = K_1 \rho^2 c^2$.

- *Claim 2*: The temperature of a gas is given by $T = K_2 \rho c^2$.

- *Now*: Combine Claims 1 & 2:

$$P = (K_1/K_2)\rho T = KT/V.$$

  - ○ K = constant.
  - ○ Volume V is inversely proportional to ρ.

- *Thus*: The volume of a gas under constant pressure gives a true measure of temperature.

- *But*: To make quantitative calculations, need to know the precise form of the force between two particles of caloric.

4. Regnault on "Comparability" and Air Thermometers.

- *The idea of "comparability"*:

> "If a thermometer is to give us the true temperatures, it must at least always give us the same reading under the same circumstance; similarly, if a type of thermometer is to be an accurate instrument, all thermometers of that type must at least agree with each other in their readings." (Chang, pg. 77.)

Regnault's (1847) results.

Henri Victor Regnault
(1810-1878)

- Mercury thermometers fail comparability: Mercury thermometers made with different types of glass display a wide range of values:

Air thermometer	Mercury with "Choisy-le-Roi" crystal	Mercury with ordinary glass	Mercury with green glass	Mercury with Swedish glass
100 (°C)	100.00	100.00	100.00	100.00
150	150.40	149.80	150.30	150.15
200	201.25	199.70	200.80	200.50
250	253.00	250.05	251.85	251.44
300	305.72	301.08	--	--
350	360.50	354.00	--	--

(Chang, pg. 80.)

- Air thermometers display comparability:

Air thermometer *A*		Air thermometer *A'*		
Pressure (mmHg)	Temperature reading (°C)	Pressure (mmHg)	Temperature reading (°C)	Temperture difference (*A* - *A'*)
762.75	0	583.07	0	0
1027.01	95.57	782.21	95.57	0.00
1192.91	155.99	911.78	155.82	+0.17
1346.99	212.25	1030.48	212.27	-0.02
1421.77	239.17	1086.76	239.21	-0.04
1534.17	281.07	1173.29	280.85	-0.22
1696.86	339.68	1296.72	339.39	-0.29

(Chang, pg. 81.)

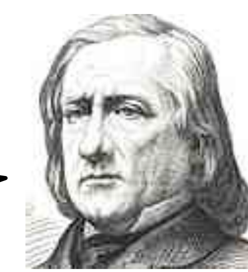
"One can therefore conclude with all certainty from the preceding experiments: the air thermometer is a perfectly comparable instrument even when it is filled with air at different densities."

- *Moreover*: Not all gases are identical in behavior:

Air thermometer A		*Sulfuric acid thermometer A′*		
Pressure (mmHg)	Temperature reading (°C)	Pressure (mmHg)	Temperature reading (°C)	Temperture difference (*A* - *A′*)
762.75	0	588.70	0	
1032.07	97.56	804.21	97.56	0.00
1141.54	137.24	890.70	136.78	+0.46
1301.33	195.42	1016.87	194.21	+1.21
1391.07	228.16	1088.08	226.59	+1.57
1394.41	229.38	1089.98	227.65	+1.73
1480.09	260.84	1157.88	258.75	+2.09
1643.85	320.68	1286.93	317.73	+2.95

(Chang, pg. 82.)

"The air thermometer is the only measuring instrument that one could employ with confidence for the determination of elevated temperatures; it is the only one which we will employ in the future, when the temperatures exceed 100°."



5. The Extension of Observability.

> "The improvement of measurement standards is a process contributing to the general expansion and refinement of human knowledge from the narrow and crude world of bodily sensations." (Chang, pg. 84.)

- *Empiricism* = sense experience is the ultimate basis for knowledge.

> - *Constructive Empiricism* = Science provides reliable knowledge of observable phenomena; science does not provide reliable knowledge of unobservable phenomena. (van Fraassen 1980)
> - *Observability* = An in-principle perceivability by unaided human senses.

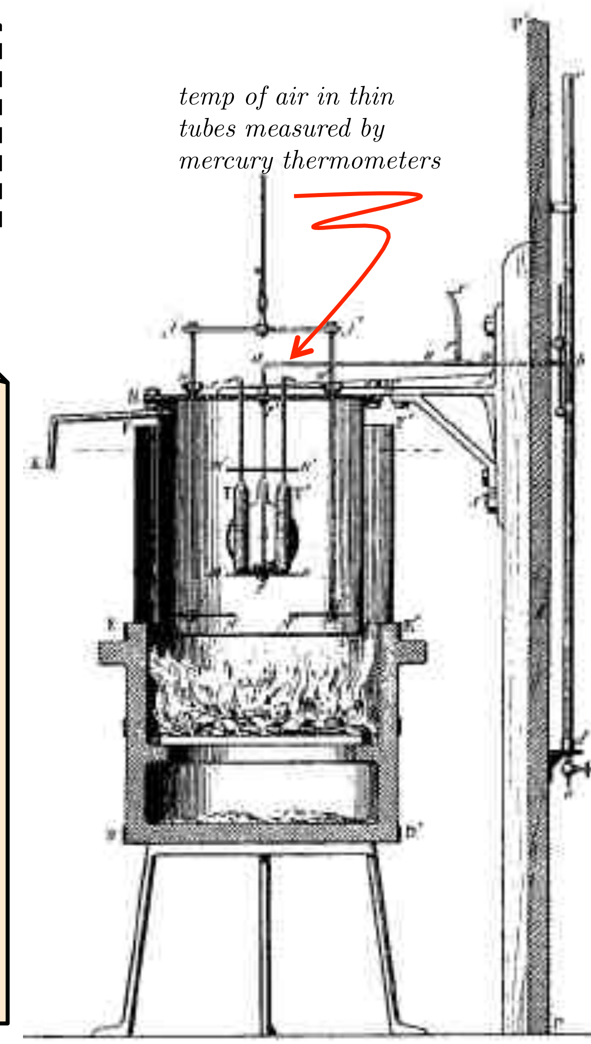
- *But*: Is there a clear line between the observable and the unobservable?
  - *Dinosaurs?*
  - *Bacteria?*
- Is observability contingent on history and scientific progress?
- Chang, pg. 86: *Observation* = *reliable* determination from sensation.
  - "What is more important is a comparative judgement, so that we can recognize an enhancement of observability when it happens."

- "Regnault's contribution to thermometry was to enhance the observability of temperature as a numerical quantity, and to do so without relying on theories."
  - *Non-theoretical criterion of reliability = comparability.*
- *<u>But</u>*: Regnault used mercury thermometers in his air thermometer!

"How was the use of the mercury thermometer allowable, when it had not been validated (worse yet, when Regnault himself had discredited it)?" (Chang, pg. 87.

<u>Legitimate for the following reasons:</u>

1. Amount of air in thin tubes was small, so discrepancies in temperature readings would have been small.
2. Failure of mercury thermometers at low temperatures in thin tubes was not severe.
3. Mercury and air thermometers were comparible between 0 and 100, and not too far above 100.
4. The test was done by checking comparability in the final readings, not by justifying how those readings were obtained.



6. The Ontological Principle of Single Value.

- The criterion of comparability assumes the "principle of single value":

> *Principle of Single Value*
> A real physical property can have no more than one definite value in a given situation.

- An *ontological* principle that cannot be justified by either logic or experience.
- *Ontological principles* = "Those assumptions that are commonly regarded as essential features of reality... [They] are always valid because we are not capable of accepting anything that violates them as an element of reality."
- *But*: "It is possible that our ontological principles are false."

> "There is no guarantee that human sense organs have any particular aptitude for registering features of the world as they really are... Similarly I believe that we should do our best to improve our ontological principles rather than giving up the practice of specifying them and using them in evaluating systems of knowledge." (Chang, pg. 92.)

7. Minimalist Overdetermination.

- The "Hypothetico-Deductive" (HD) method of hypothesis-testing:

If H is true, then O is true. ← *Determination of a quantity O by deduction from a hypothesis H.*

O is true. ← *Determination of a quantity O by observation.*

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Therefore H is confirmed.

- A particular example of...

> <u>*Overdetermination*</u>:
>
> "A method of hypothesis testing in which one makes multiple determinations of a certain quantity, on the basis of a certain set of assumptions. If the multiple determinations agree with each other, that tends to argue for the correctness or usefulness of the set of assumptions used. If there is disagreement, that tends to argue against the set of assumptions." (Chang, pg. 93.)

The Holism Problem in theory-testing

"An experiment in physics can never condem an isolated hypothesis but only a whole theoretical group."

Pierre Duhem
(1861-1916)

Holism Problem for HD:

If (H & A_1 & A_2 & ...) are true, then O is true.
O is true.

Therefore (H & A_1 & A_2 & ...) is confirmed.

- *But*: Which of (H & A_1 & A_2 & ...) does O confirm?

Holism Problem for Falsificationism:

If (H & A_1 & A_2 & ...) are true, then O is true.
O is false.

Therefore (H & A_1 & A_2 & ...) is false.

- *But*: Which of (H & A_1 & A_2 & ...) does O falsify?
- We can always retain H and reject one or more of the auxiliaries.

- De Luc's tests for the mercury thermometer:
  - *Required auxiliary hypotheses: the conservation of heat and the constancy of the specific heat of water.*
- Regnault's tests for the air thermometer:
  - "...managed to arrange overdetermination without recourse to any significant additional hypotheses concerning heat and temperature..." (Chang, pg. 94.)

> *Minimalist Overdetermination*
>
> Version of overdetermination in which all possible extraneous (or auxiliary) non-observational hypotheses are removed.

- "Minimalism can create a stronger assurance about the verdict of a test when there is a verdict, but it cannot ensure the existence of a clear verdict."
  - *Suppose there had been different types of thermometers, each type passing the comparability test, but differing from the other types.*
  - *Suppose no type of thermometer had passed the comparability test.*