Lecture: Foundations Thermo & SM — 2nd Law & Irreversibility 17 Jan 2018

[use simple, lovely proof of ent increase by Maxwell, *Theory of Heat*, ch. VIII, p. 163]

Outline

— Read Eddington's remark, quoted in "Bluff Your Way", p. 310; also Einstein remark; also remark by Planck quoted in 'Bluff', p. 356

1) Uffink's 3 kinds of reversibility
2) 2nd Law of irrev in thermo
   - Maxwell's eg
   - K/C/P Postulates; heat & work
   - Uffink on Planck; — Lieb-Yngvason (on ent letter) } "involves time" (re: invariance principles w/r/t adiab processes; though not nec'y of adiab. cycles)
3) BSM
   - Boltzmann's Law; micro-dyns; ~~initial state counting~~
   - high-prob'y past
   - Loschmidt's objection
   - Zermelo
   - initial-state counting

Reversibility — Varieties

for theory T, all, not just thermo

— TRI —

1) space of states Γ
2) process / dyn'l evol as parametrized curve (param = time)

$$P = \{\sigma_t \in \Gamma : t_i \leq t \leq t_f\} \quad \begin{pmatrix} i = \text{init} \\ f = \text{final} \end{pmatrix}$$ subset of all curves on Γ

3) involution R on Γ : $R(\sigma)$ = "time-reverse"

   (e.g., additive inverse of momentum, identity on config, in CM)

4) time-revers process: $P^* = \{(R\sigma)_{-t} : -t_f \leq t \leq -t_i\}$

⇒ T is TRI if set of paths closed und time-reversal

remarks: 1) not 'metaphys'; just math'l struc of theory
2) we don't really contemplate "reversing time itself" only which process the theory admits as possible in actual world (not whether they actually do occur)

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- Quasi-static – for processes
  - therm SoS
    - curve on thermo T s.t. each "step" differs infinitesimally from equil state
  - no notion of time
  - holds only approx (T has only equil states) – ignore Norton/Valente
  - such curves approx reversible in sense that going either direction in phys'l world is allowed (subtlety: generically the "forward" and "backward" procs not identical, but "differ by infinitesimals" – put aside)

- Irrecoverable – for procs
  - proc s.t. transition from initial to final state cannot be undone – can never fully return to σ_i but also including states of all auxiliary syss ("environment")
  - ⇒ no specification/analysis of individ/particular procs
  - let σ be state of sys, Z that of envir; then envisioned is

$$\exists P : \langle \sigma_i , Z_i \rangle \to \langle P(\sigma_i), P(Z_i) \rangle := \langle \sigma_f , Z_f \rangle$$

P is recoverable iff $\exists P^* : \langle \sigma_f , Z_f \rangle \to \langle \sigma_i , Z_i \rangle$

⇒ These 3 are independent in sense that a theory/proc can be 1 w/o other 2 (except TRI may imply recoverable, depending on whether one interprets environment as "thermo" or not)

1) pendulum is recoverable and TRI but not quasi-static
2) discharge of condenser (capacitor) can be made quasi-static but is not TRI or recoverable
3) Lieb-Yngvason: irrecoverable w/ quasistatic w/o TRI; 4) irrecoverable, not quasi-static or TRI: reverse proc not reverse steps of original

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independence of TRI & Recoverability

(from hereon we ignore ~~actuality of~~ quasi-statics as possible fundamental notion of 'reversible')

1) recovery is only achievement of initial state; no specification of process that do this required
2) complete recovery, not just state in sys's SOS

3) "possible" = in actual world, not just in some model of theory (possibly incompatible w/ real world, e.g., if universe had started out w/ diff't initial temp and pressure)

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Problem of Env, External Interventions

- Uffink: thermo has no eoms, coz procs occur only after external interventions
  ⇒ non seq! even if primary claim about external interventions is true (I doubt it – "external intervention" that put thermo procs in local equil in Sun started?), ∃ could still eoms after external intervention
    ⇒ would be no worse than role of measurement in "standard QM"
- for recoverability, we deal w/ complete states of environment
  1) that may not be tractable by thermo in 1st place
  2) if one takes "recoverability" as fundamental, uses it as basis for defining 'temp', 'entropy', etc., then ∃ apparent circularity when environment is treated by thermo, since it seems we need to attribute temp, entropy, etc., to environment in order to use recoverability + define temp, entropy, etc.
  3) must restrict to 'parts of env that interact w/ sys', not, e.g., radiation from star in distant galaxy
⇒ I think – not really problematic
- we can do everything we need using only thermo syss as "environment"
- rel'n between recoverability and defin's of temp, entropy, etc., can be dialectical, as in intro, defn of mass in Newton's few in Principia

Uffink on Recoverability & Time

- since they involve reference to 'actual procs', ∃ immediate intrinsic rel'n to asymmetry in time

1st: remarks about Gibbs (no time for detailed eval'n, discussion in lect)

- his ("2nd Law") princs are for states of stable equil – not about procs, and so prima facie independent of temporal concepts
- tendency towards temporal increase in entropy can't be derived from it

⇒ "recoverab" is intimately related to TRI but not identical w/ it
→ but one can sensibly ask: does TRI imply recoverability?

Uffink: 2nd Law based on cycles is not TRI

- Kelvin & Clausius cyclic-version Postulates do not imply irrecoverability

- "entropy increase" by itself not implies not-TRI;
  - Lieb–Yngvason derive it w/o temporal concepts

My View

- Clausius & Kelvin Postulates do not rely on or imply anything about procs making fundamental use of temporal notions
- rather asymmetry in exchangeability of heat into work & vice versa, as they are prior to consideration of 'direction' of procs and change of entropy
- they do imply irrecoverability
  (all argued for in previous lectures – see also Maxwell's arg, Theory Heat, p. 163, ch. VIII

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BSM

- recall "Boltzmann's Law" (version of H-theorem)

⇒ explicit reference to, dependence on temporal concepts

→ unavoidable

1) Problem of highly probably high-entropy past

a) micro-dyns TRI; Statistical Postulate (given sys in macrostate M, then prob'y it's in A (macrostate) is μ(A)/μ(M))

b) if highly probable for low-entr microstate to evolve future-towards high-entr micro/macro-state, then it is highly likely to have evolved to low-entropy microstate from high-entropy macrostate

⇒ given enormous size of high-ent macrostates relative to low-ent, most of time of universe must be in high-ent state

→ our local low-ent state is merely "unlikely statistical fluctuation away from high-ent equilibrium" ("Boltzmann brains")

⇒ prob of justification/confirmation for theory? we see only what theory predicts w/ low prob'y!

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Loschmidt's Reversibility Objection

2nd Law can't always hold!

(1) TRI of micro-dyns; (2) assume that $S(M) = S(R(M))$ for all macrostates M (reasonable, since entropy depends only on magnitude and relative orientations of momentum, which are preserved under R)

Now - if $S(M_i) < S(M_f)$, $t_i < t_f$, and ∃ process $M_i \rightarrow M_f$, then ∃ process from $M_f \rightarrow M_i$, so we get: transition to higher entropy possible iff transition to lower entropy also possible

⇒ transitions allowed by micro-dyns not allowed by macro-dyns

Why? standard answers: 1) put in asym 'by hand' (e.g., Boltz's Stosszahlansatz)
2) stipulate "special" initial conds (e.g., Past Hypothesis)

Zermelo's Recurrence Objection

Entropy can't always increase!

- Poincaré recurrence thm
  1) compact phase space (available region in BSM T)
  2) Ham'n dyns (BSM microdyns) ("non-trivial")

⇒ given any initial state, after a finite interval of time, sys's state will return "arbitrarily closely" (as close as one likes, depending on interval) to initial state

⇒ since S is continuous func, it must begin to monotonically decrease somewhere along the way, if it ever decreased (or vice-versa!)

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responses to Zermelo?

standard): "recurrence time" is unphysically large, e.g.,
$\sim 10^{10^{23}}$ secs for bottle of water, so we never observe it

- but: this misses the point - who cares whether we observe it; it's still the case that entropy non-decrease will necessarily fail for long periods according to the theory itself!

Initial State Counting

1) pick any microstate:
   a) if high-ent, ergodicity guarantees it must eventually go to low-ent state
   b) if low-ent, 2nd Law guarantees it must eventually go to high ent

⇒ for every low-ent to high-ent process there is a corresponding high-to-low
   ⇒ high-to-low is same cardinality as low-to-high
⇒ how can "probability" guarantee that 2nd Law holds?
   (measure-theoretic notions)

⇒ once again, note how weird modal character of entropy plays crucial role, this time contrary to 2nd Law (for high-prob past as well)

- responses? standard ones are similar to reversibility
   1) stipulate asym cond "by hand"
   2) specify that init conds "always special"

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Common attempts to answer all 4 of those probs

1) real syss are finite: does away w/ recurrence; but not reversibility; not relevant which universe, equally
. (but it's not clear how to treat whole uni as a single dyn'l sys in relevant sense – quantum cosmology?)

2) real syss are not isolated:
- coupling w/ coarse-grained external syss à la Zwanzig and Master eqns (ubiquitous in real phys – see Wallace "Arrow of Time in Phys") can address reversibility prima facie
- but 3 probs
i) we can always expand sys at issue to include enough of env to make it effectively isolated (ex hypothesi – see discussion by Maxwell in Matter & Motion) → again, ultimately turns on question of quantum cosmo
ii) begging the question: we must assume env is "random" or "uncontrolled" in way that already assumes it has irreversible properties, since that's just time-reverse of sys w/ "special" init conds → "interactions w/ random noise"
iii) real life "isolated syss" can manifest seemingly irrev behavior (spin-echo, e.g. – but this is problematic/controversial, since orig'l state can be restored by interaction w/ env – recoverable, in Kelvin/Planck sense?)

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3) fundamental laws not TRI? we know experimentally

a) that weak nuclear force is not (kaon decay), and have strong theor'l grounds for thinking that it holds for strong-force interactions, both via CP violations
(non-observation of electric dipole moment of neutron)

i) mostly dismissed by ppl of phys as too weak and rare to account for macroscopic irrev

ii) but – that dismissal is too quick: weak-force TRI-viols play crucial role in some macro phenomena of fundamental of universal importance: baryogenesis (more matter than anti-matter in uni) and nucleosynthesis (ratios of H, He & Li production) in early universe – both still govern in large part evol of all later-time cosmo and even fine-details of, (e.g), stellar and planetary evolution

5) quantum wave-collapse? too controversial and too few hard results to really have principled discussion – almost entirely a matter of personal preference for "interp" of QM

4) Special Init Conds

1) postulate constraint on initial microstate: usually 'probabilistic' – init microstate drawn 'at random' from (relative to some 'phys significant' initial prob'y distr) subject to constraint that subsequent evol'n is consistent w/ current macrostate

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a) probs with 4) i): doesn't solve prob of high-ent past (see these notes, p. (5)) unless one picks init cond "at very start of universe", macrostate, that is low-ent
→ but then what the fuck does it mean to have a prob'y dist over those initial states, and more problematically, to "draw one at random"?!
(Penrose's conceit of the Creator throwing a dart at phase space w/ appropriate constraints on possible paths of the dart?!)

- picking macro state at start of universe known as "Past Hypothesis", very popular, but note that it consists of 2 parts (not 1, as focused on in literature)
(i) prob'y dist over microstates appropriate for initial time
(ii) conditionalized on early time macro state

b) probs w/ total Past Hypo:
1) no constructive way, only hand-waving args
and my theorem about Borel measures on ∞-dim Fréchet spaces strongly suggests no constructive way can be had
2) noting that ∃ in fact the conds seemed to have held lends an observation obviates it as an explanation - unless one posits init conds as something like a law of nature!
(cf. Penrose's Conformal Curvature Hypothesis)

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Fifth way not discussed in literature

(5) constraints imposed by geometry of physical system

- volcanic eruptions consist of lava flowing out of cone; geometry makes it highly unlikely for lava to flow back in
- balance perfect die with flattened corners, on its corner - slight perturbation sends it to rest on its side
  start w/ resting on its side, slight perturb never sends it to balancing on its corner

this seems promising - problems w/ it in principle? applicable at all to cases of interest here? (BSM)?