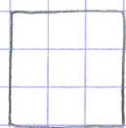
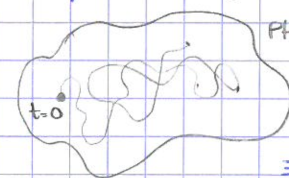
1 Introduction / 2 coarsening processes / 3 formalism / 4 Dynamics of disordered spins spins.
Lecture notes LFC, LES HOUCHES (2002).

Lecture 1:
1 Eq vs non eq
2 How can a classical system stay far from equilibrium?
3 Details on the non eq

1- Equilibrium vs non equilibrium systems.

First consider closed (≠ open) yet out of equilibrium systems (e.g. cold atoms systems)

CLOSED  → let evolve a classical system at constant energy $\mathcal{E}$



→ will it cover the full subspace of energy $\mathcal{E}$ ≡ reaching MICROCANONICAL EQUILIBRIUM.

We usual just assume so, but the question of how do we get there belong to "ergodic theory" of mathematical physics (interest boosted by quantum isolated systems).

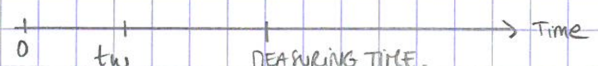
QUESTION:
After a rapid variation (= quench) of parameters of hamiltonian $H(\lambda)$, $\lambda_I \to \lambda_F$, what happens?

Now open system in equilibrium.

out of equilibrium
now a quench ≡ change of caracteristics of the bath, e.g. $T_I \to T_F$.

how to describe the statics and dynamics of a classical system coupled to a classical environment.

mechanical point of view $\{\vec{\xi}_i(t)\}$:



WAITING TIME
↳ reach G. Boltzmann distribution?

↳ all systems will have a teq, such that if measuring at $t \gg$ teq → all conditions we'll precise for equilibrium are verified.
$t <$ teq → out of equilibrium.

necessary conditions:
- bath must be in equilibrium
- all forces in/applied to the system must be conservative $\vec{F} = -\vec{\nabla} V$.
- initial conditions → sampled from bath eq. distribution
  or possibility to wait for teq $P_{eq} \propto e^{-\frac{mv^2}{2} + V(\vec{r})}$

two properties to check for equilibrium: (not sufficient again)
→ one time quantities should not depend on time: $\langle A(\{\vec{\xi}_i\}_\xi)(t)\rangle = \langle A(\{\vec{\xi}_i\})\rangle_{eq}$.
noise Langevin process ↗ aver.
→ all time correlations functions are stationnary: $C(t, t_w) = C(t - t_w)$
≡ time translational invariant $C(t_1, t_2, .. t_n) = C(t_1+\Delta, t_2+\Delta, .. t_n+\Delta)$

2- How can a classical system stay far from equilibrium

FROM SINGLE PARTICLE TO MANY BODY: - microscopic systems with non confining potential DIFFUSION

→ DIFFUSION

Phenomenological description → follow Langevin: $m\dot{v}_a = -\gamma_0 v_a + \xi_a$

$\langle \xi_a(t) \rangle = 0$

$\langle \xi_a(t) \xi_a(t') \rangle = 2\gamma_0 k_B T \, \delta(t-t')$

⇒ the double occurence γ_0 ensures that asymptotically $\langle E_c \rangle$ → equipartition!

$t \gg t_v^* \equiv m/\gamma_0$ inertia time

↳ take 1 particle in 1d: $\begin{cases} \langle m v^2(t) \rangle \to k_B T \\ \langle x^2(t) \rangle \to 2Dt \end{cases}$ → non constant one time observable

$D = k_B T / \gamma_0$

⇒ out of equilibrium.

↳ although velocities seem equilibrated!

coexistence of variables with ≠ behavior!

Rk: non confining potential $P_{eq}(x) \propto e^{-\beta V(x)} = 1$ ⇒ not normalizable!

→ PHASE SEPARATION

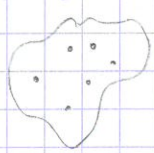
e.g. demixing transitions (water in oil, repulsive interactions)

we'll see tomorrow that the equilibration time of such problems go as: $t_{eq}(L) \sim L^{1/z_d} \xrightarrow[L\to\infty]{} \infty$ (dynamic exponent)

→ QUENCHED DISORDER - GLASSES

quenched variables are frozen during time-scales over which other variables fluctuate.

e.g. spin glasses



fixed random positions of impurities carrying spins

$V(s_i, s_j) \propto g(|\vec{r}_i - \vec{r}_j|) \, s_i s_j \equiv J_{ij}$ random $\sim P(J_{ij})$

structural glasses.

↳ what we do not know and would like to understand in these problems?

↳ systems with competing interactions ≡ frustration, out of equilibrium...

→ phase transitions? what is the low temperature phases nature?

what are the mechanisms of relaxation? the dynamics?

TOOLS: → static / dynamic mean field theory → reproduce <u>some</u> aspects.

→ ACTIVE MATTER

3 Details in the non-equilibrium behavior

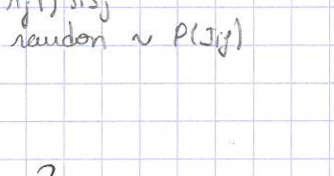
DYNAMICAL CLASSES → structural glass look like mixed 1st-2nd order transition

→ spin glass look like typical 2nd order transition (if it exist).

↳ A family of models that capture these pheno Kirkpatrick... late 80's

CORRELATION FUNCTIONS → recall no change in spatial structure

→ but dramatic increase of relaxation time.



RESPONSE TO PERTURBATION ≠ spontaneous relation, new induced relaxation!

↳ out of equilibrium relaxation

STILL AT LOWER TEMPERATURE q_{EA} ≡ depends on T for $T < T_g$

$C(t, t_w; T < T_g) \neq f(t - t_w)$

↳ ageing effect, depends on the waiting time