Enzymatic degradation of plastics waste: a geometric model

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Polyester waste: recycling by enzymatic de-polymerisation?

PET bottle waste

96% after 24h

PET textile waste
swimwear
lining

82%

PET fiber waste
automotive scrap

36%

PET/PBT textile
swimwear
trunk

15%

PBT

0%

What do enzymes need?

enzymes act only at the **surface**

they "need space" to act:
- **amorphous** substrate (avoid crystals!)
- substrate **mobility** (avoid glass!)

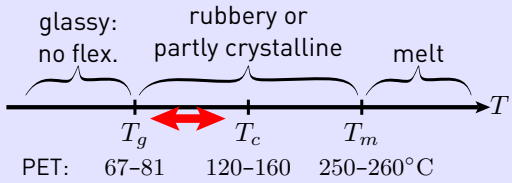
natural temperature range (enzymes are proteins)
- roughly 40–$70^\circ\mathrm{C}$

water

Prepare the polyesters:

prepare:
- melt + quench
- mill + sieve: break into pieces $\sim 300\,\mu m$

de-polymerise:



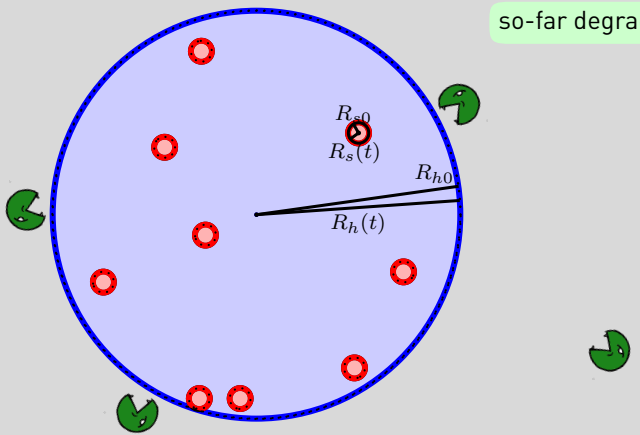
initial crystallinity + nucleation
crystal growth!

The growing crystallites are a problem!

Competition: de-polymerisation vs. crystal growth

model: one shrinking sphere: amorphous material: degradable

many growing spheres: (partly) crystalline material: not degradable



parameters: N_s, $\dot{R}_s/\dot{R}_h$, R_{s0}/R_{h0}, $[\dot{N}_s]$

depend on material, composition, preparation, processing temperature, ...

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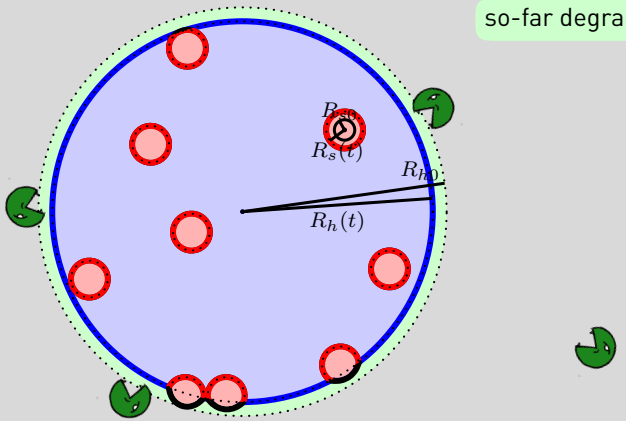

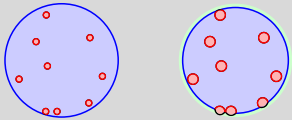

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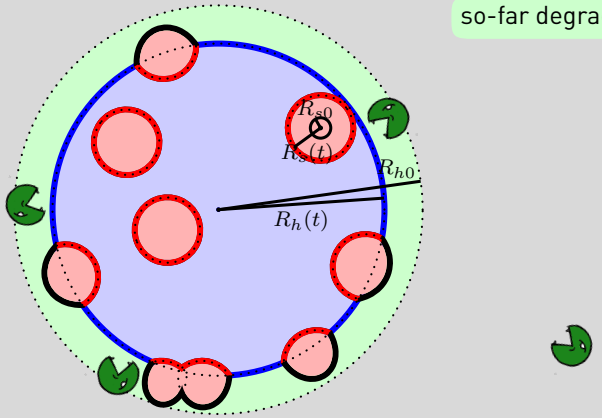

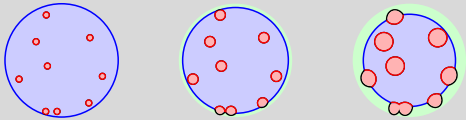

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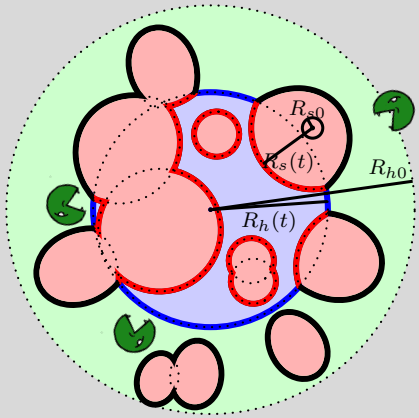
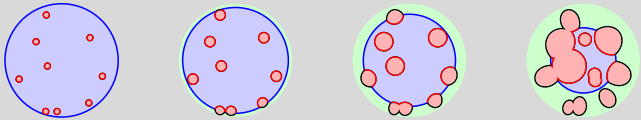
so-far degraded material





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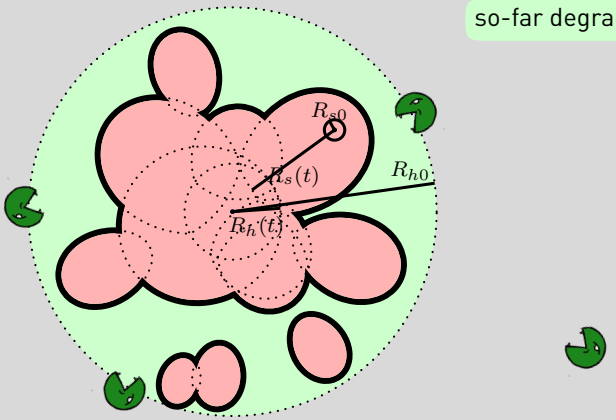

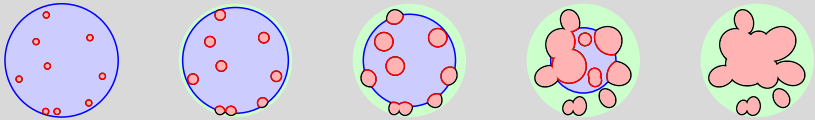

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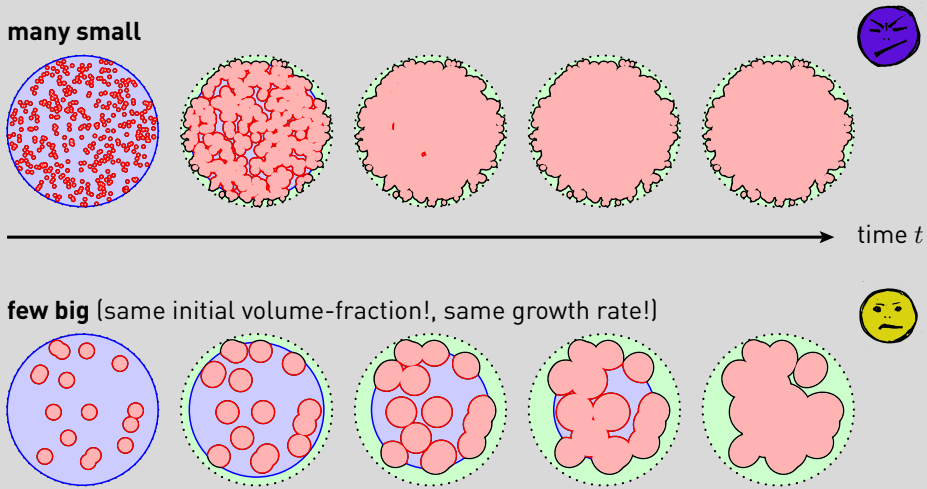
depend on material, composition, preparation, processing temperature, ...

Competition: de-polymerisation vs. crystal growth

careful! there is more than just the total initial crystallinity



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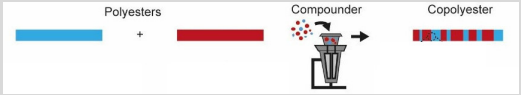
depend on material, composition, preparation, processing temperature, ...

How to slow down crystallisation?

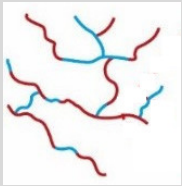
“Classic” optimisation: understand the parameters for every material
including their temperature dependence, . . .
sort materials (!?)
optimize parameter compromises
repeat the procedure also for mixtures (!?)

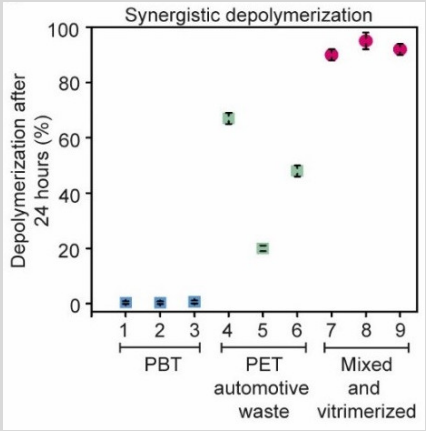
Radical new idea: **Mixing rather than sorting**

melt transesterification: increase randomness along chains
works for blends: 75%+25% of PET+PBT or of PET+PTT



vitrimerisation:
cross-link chains to form a random network





This was really a group effort:

Ludwik Leibler (Gulliver lab, CNRS)

Andrew Griffiths (Biochemistry lab, ESPCI)

Hernan Garate (SIMM lab, ESPCI/CNRS/PSL)

Yannick Rondelez (Gulliver lab, ESPCI)

. . . and me (Gulliver lab, CNRS). . .

and Costantino Creton (SIMM lab, CNRS)

and Clément Freymond (SIMM lab, ESPCI)

and Louise Breloy (SIMM lab, ESPCI)

. . . plus industrial contacts . . .

Publication currently under review at PNAS