The Abdus Salam International Centre for Theoretical Physics

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Meeting of Modern Science and School Physics: College for School Teachers of Physics in ICTP

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Physics in a kitchen

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“Meeting of Modern Science and School Physics”, Trieste, ICTP

Physics in a Kitchen

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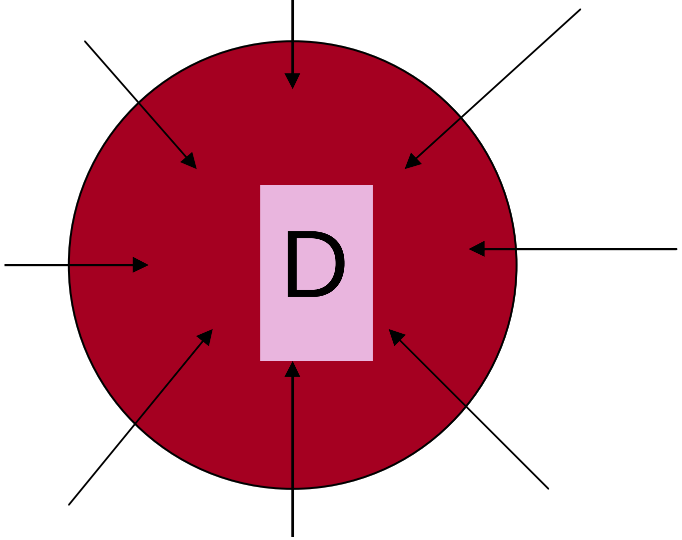
General formula for the cooking time

Heat flow



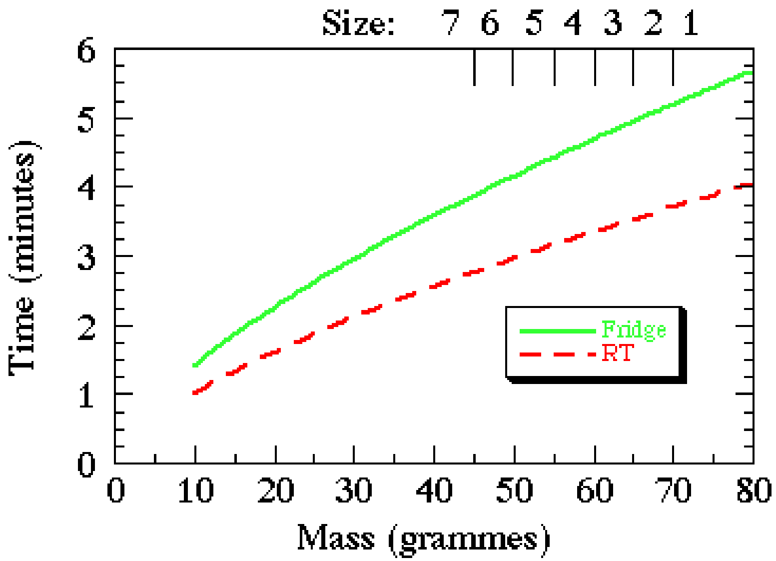
$$\frac{\partial T}{\partial \tau} = -\kappa \frac{\partial^2 T}{\partial \rho^2}$$

$$\left\lfloor \frac{1}{t} \right\rfloor = \frac{[\kappa]}{[r^2]}$$

t_{cook} = ♋👎🖹 🖃♌

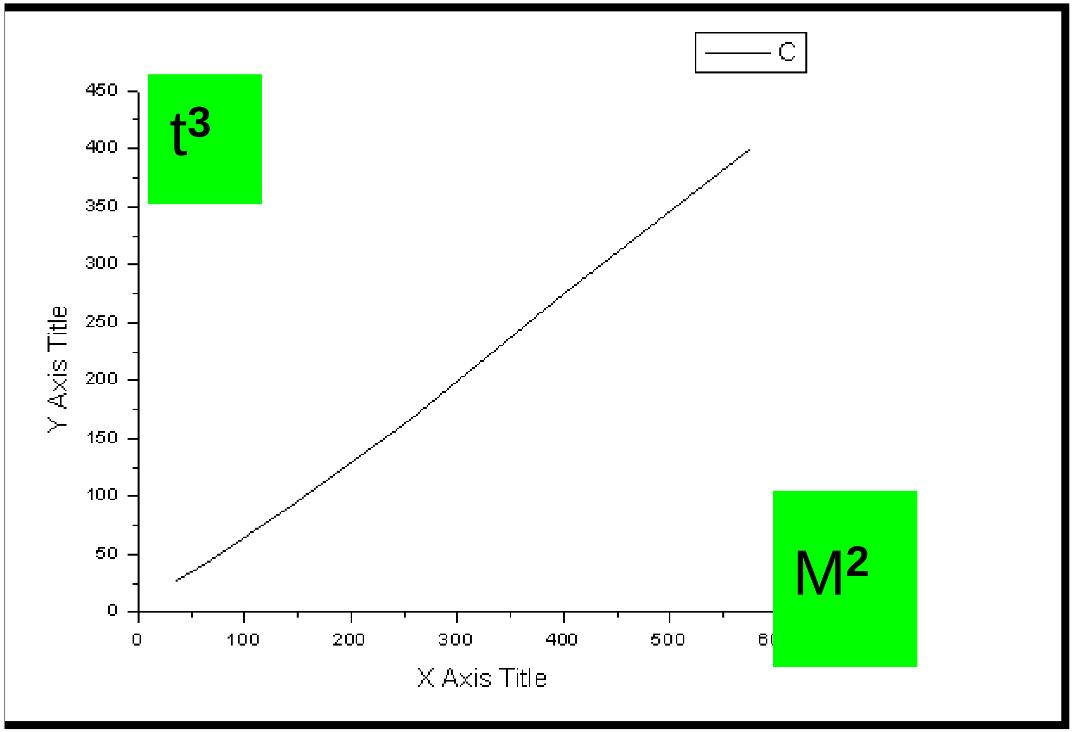
1. Egg alla “coque”

$$T_{cook} \sim M^{2/3} \log_e \left[0.76 (T_{egg} - T_{water}) / (T_{yolk} - T_{water}) \right]$$



2. The Thanksgiving day turkey secret

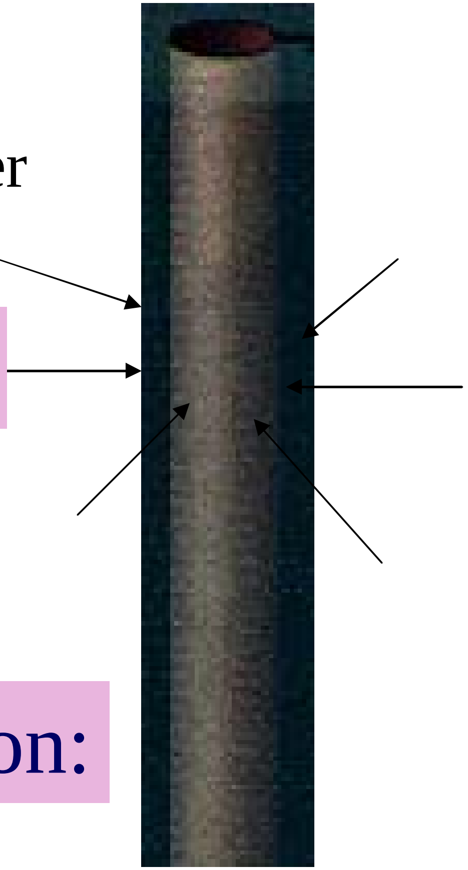
t_{cook} = ♋💣📄📪📄 🖃 ♌



Mass (pounds)	Cooking time (hours)
6	3
8	3.5
12	4.5
16	5.5
20	6.5
24	7.35

3. Physics of Pasta

Het flow and water diffusion



Heat transfer:

$$\frac{\partial T}{\partial \tau} = -\kappa \frac{\partial^2 T}{\partial \rho^2}$$

Water diffusion:

$$\frac{\partial n}{\partial \tau} = -\kappa \frac{\partial^2 n}{\partial \rho^2}$$

Cooking time: $t = aD^2 + b$

The table of cooking times for the different types of spaghetti

Tipo di pasta	Diametro est. D	Diametro int. d	Tempo di cottura sper.	Tempo di cottura teor.
Capellini n.1	1.15 mm	--	3 min	2 min
Spaghettini n. 3	1.45 mm	--	5 min	5.0 min
Spaghetti n. 5	1.75 mm	--	8 min	8.2 min
Vermicelli n. 7	1.90 mm	--	11 min	10.7 min
Vermicelli n. 8	2.05 mm	--	13 min	13.0 min
Bucatini	2.70 mm	1mm	8 min	25 min ?!

$a = 3.8$ min / mm^2

$$t = aD^2 + b$$

$b = -3$ min

The case of bucatini requires the particular treatment. The correct formula is:

$$t=a(D-d)^2+b$$

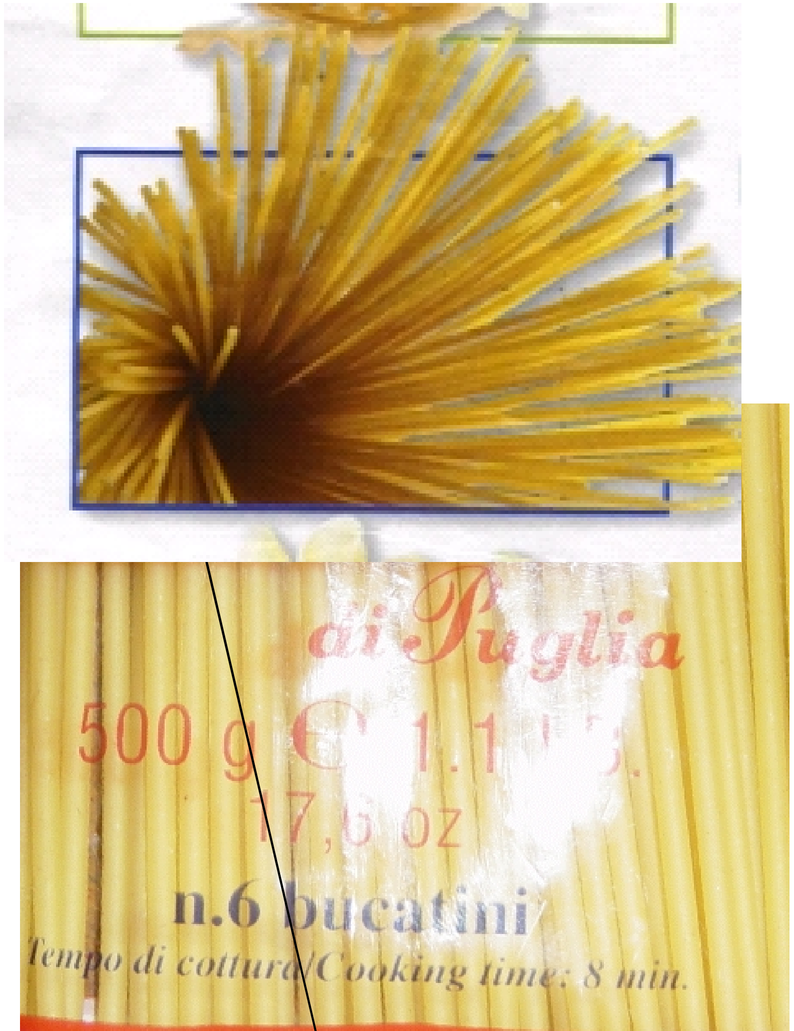
$$P=\rho gh=2\sigma/r_{min}$$

$$d_{min}=2\,r_{min}\sim 4\sigma/\rho gh$$

$h=2cm$, $\sigma=0.05$ N/m

$g=9.8$ m/s ^{2}

$d_{min}\sim 1mm$



For bucatini: $t_b=8.2$ min !

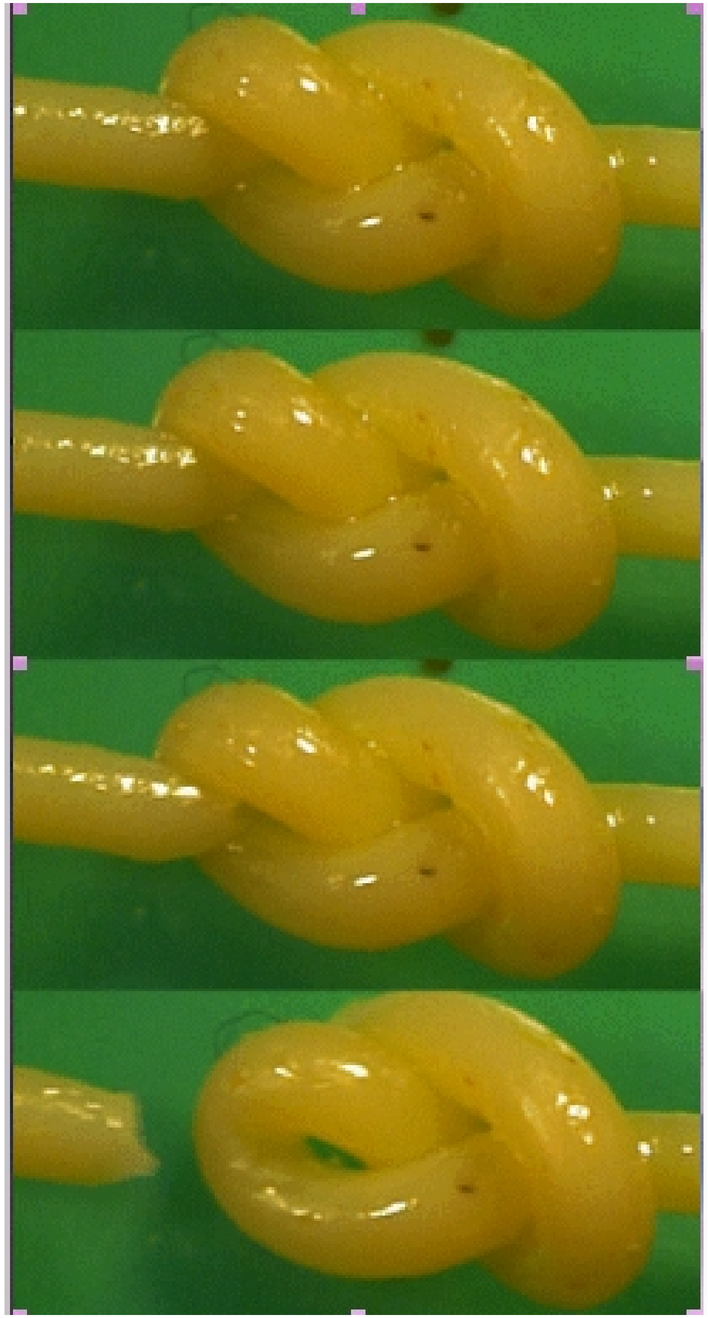
Fall down of our simple theory for too thin pasta

Capellini: d = 1.15 mm

$t_{cap} = 3.8\,[1.15]^2 - 3 \approx 2$ min

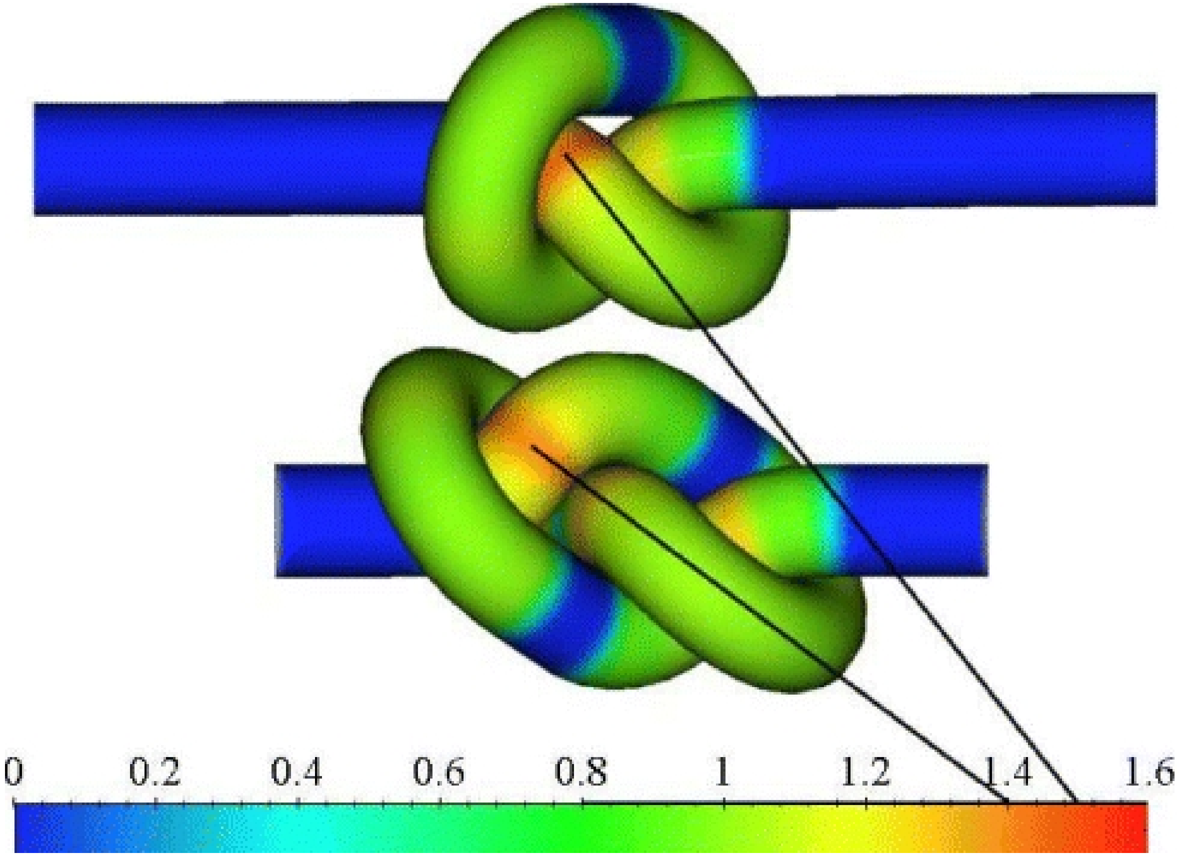
$$aD^2 + b = 0$$

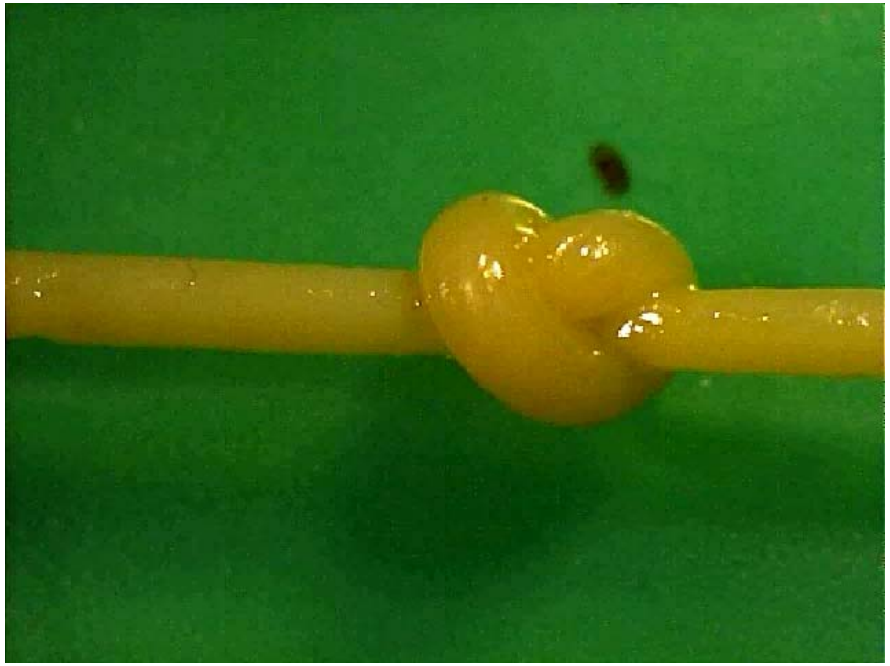
$$D_{cr} = \sqrt{|b|/a} \approx 0.85 \text{ mm}$$



Spaghetti: knotting

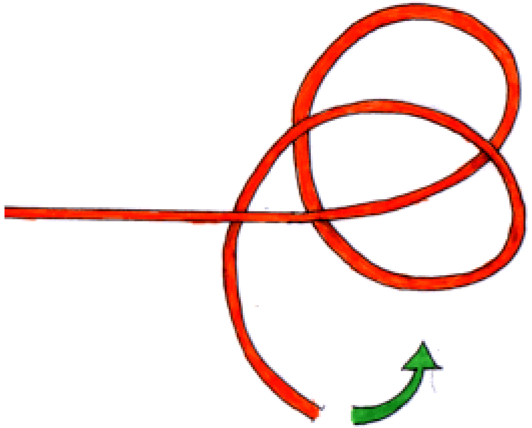
a) Help in the industrial research



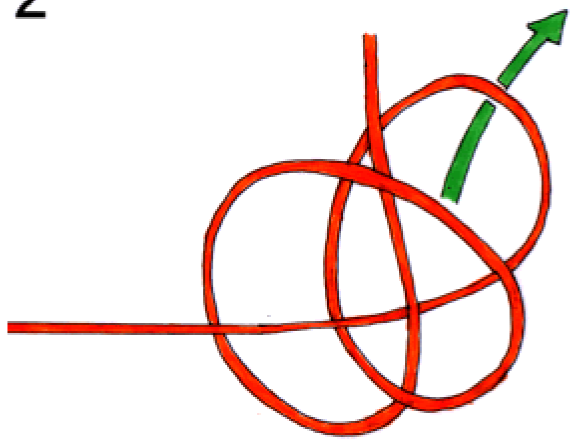


Spaghetti: knotting

1



2



$$w = 1 - \exp\left(-\frac{L}{\gamma\xi}\right),$$

$$\gamma \approx 300$$

$$\xi \sim 2 \div 3 \text{ cm},$$

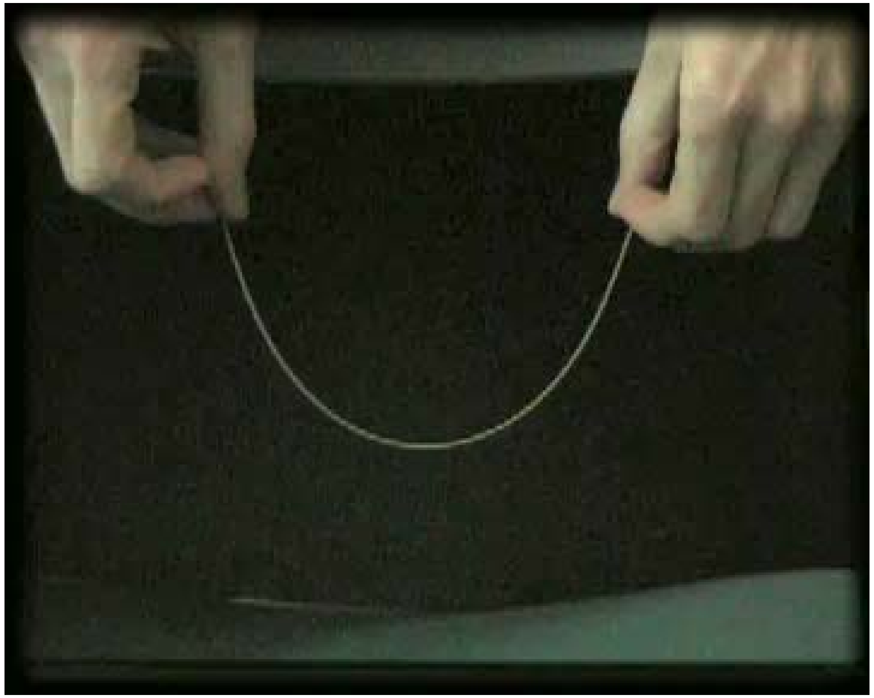
$$\exp\left(-\frac{L_{\min}}{\gamma\xi}\right) \approx 0.9$$

$$L_{\min} \approx \gamma\xi \ln 1.1 \approx 30\xi \approx 60 \div 90 \text{ cm}.$$

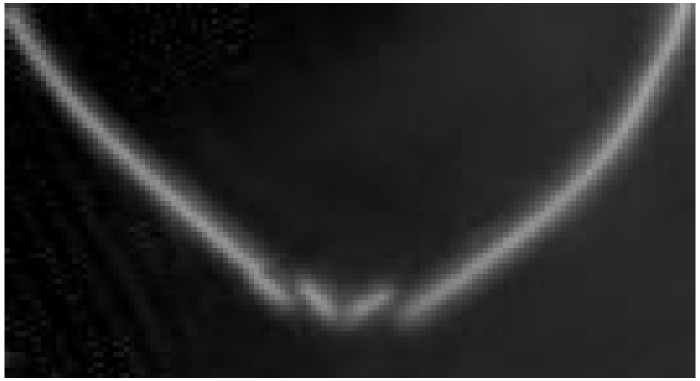
Why spaghetti do not break into two pieces?

The arc experiment

When dry spaghetto is bent beyond its critical curvature it often breaks more than into two pieces, typically 3 or 4.



Equivalent catapult experiment



The breaking dynamics:

(B.Audoli, S.Neukirch, PRL, August 2005)

$$4u''''(\xi) + \xi^2 u''(\xi) + 3\xi u'(\xi) = 0.$$

$$\xi = (s/L)/\sqrt{t/T} = s/\sqrt{(\gamma t)}.$$

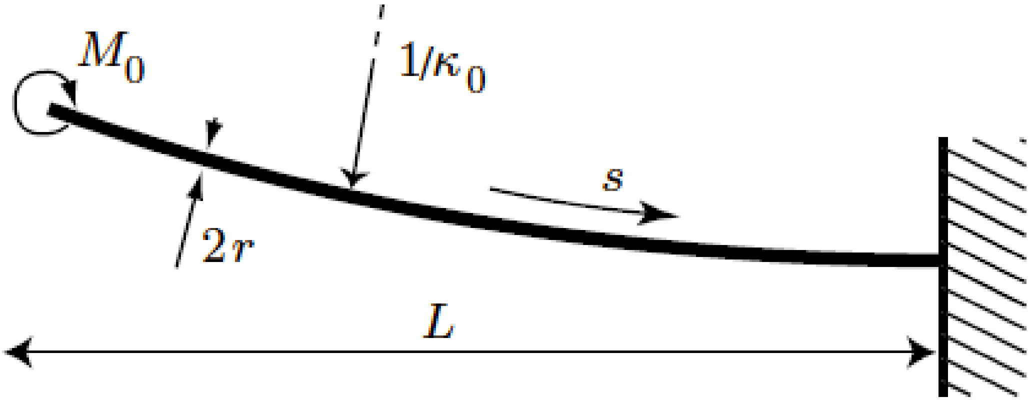


FIG. 1. The dynamics of a rod fragment following the initial breaking event in a brittle rod is modeled by releasing at time $t = 0$ a rod with fixed length L, initial curvature κ_0, and no initial velocity.

When the rod is broken, one could expect that the generated elastic waves help to both pieces of rod to relax to equilibrium.

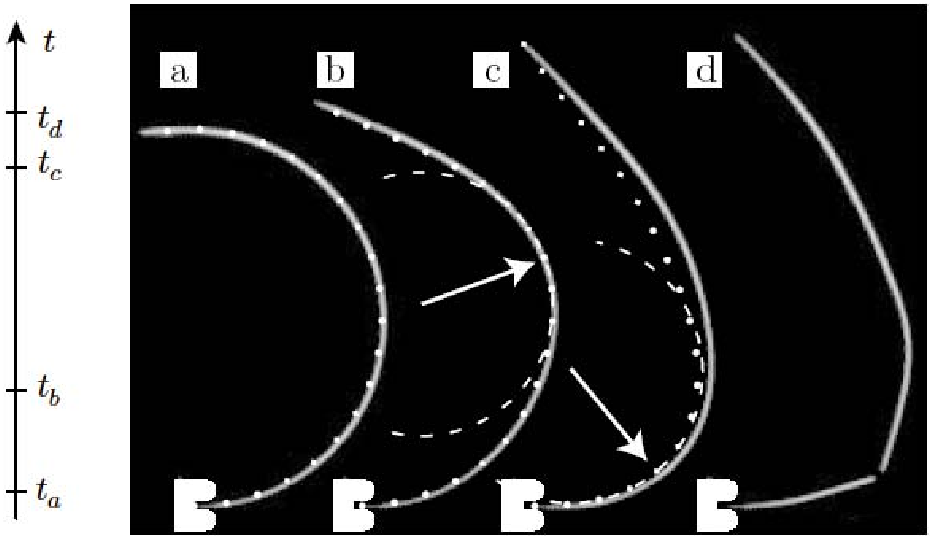
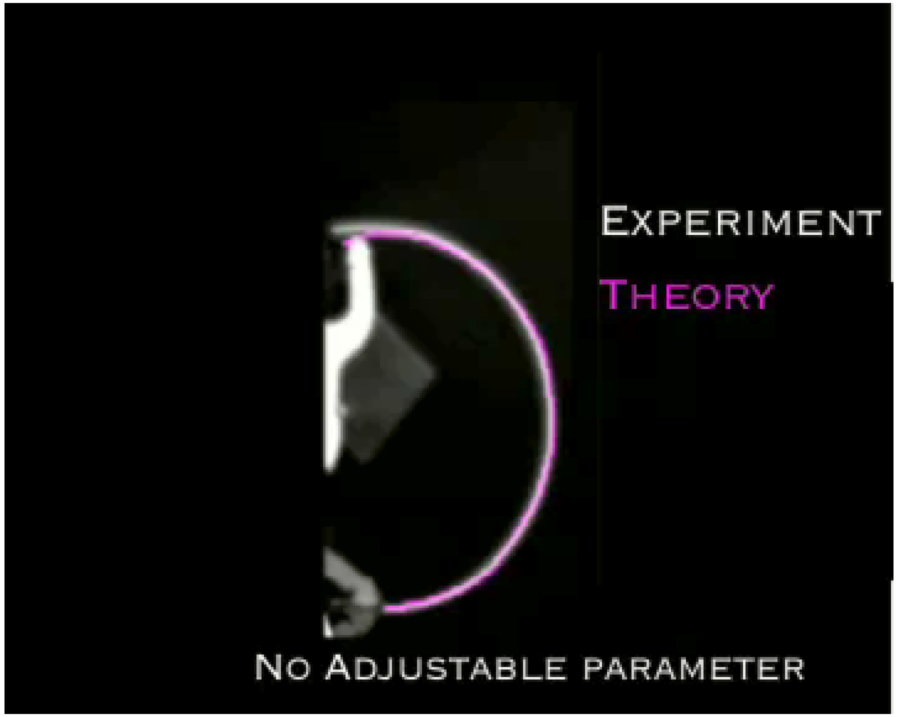


FIG. 3. A dry spaghetti is bent into an arc of circle and suddenly set free, while its lower end remains clamped. Its subsequent dynamics exhibits a local increase of curvature. Selected frames shot with a fast camera at 1000 Hz: (a) release $t_a = 0$, (b) intermediate frame $t_b = 0.0159T$, (c) frame just before rupture $t_c = 0.0509T$, and (d) frame after rupture $t_d = 0.0596T$. Predictions of the self-similar and numerical simulations based on Eq. (1) are superimposed, without any adjustable parameters: rod profile (dotted line) and osculating circle (dashed lines) at the point of largest curvature (arrow). Note that the rod breaks at the point of maximal curvature.

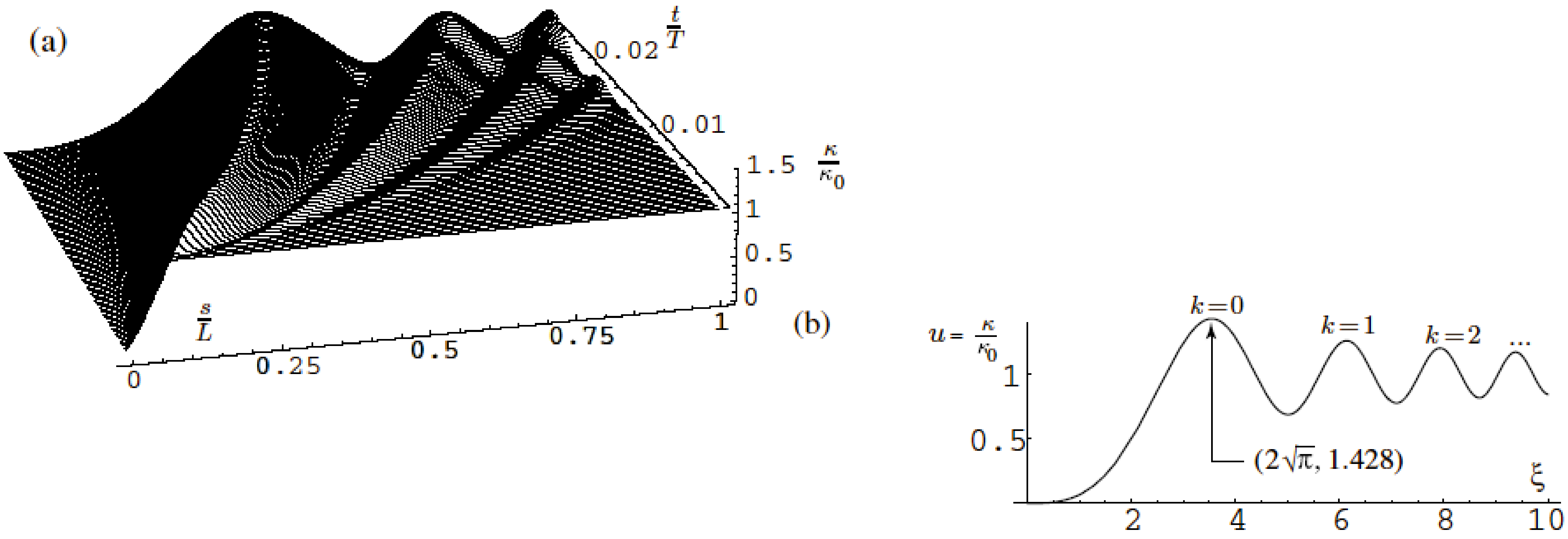
Invece, si verifica che queste onde aumentano lo stress locale, rendendo probabile la rottura della bacchetta anche in altri punti. Ne consegue una frammentazione.

The breaking dynamics



Fast camera

Fast removing of the constrain from the extremity of the half-rod results in generation of the elastic wave:



Simul.mov

FIG. 2. (a) Numerical solution of the Kirchhoff Eq. (1) with clamped-free boundary conditions, for a uniform initial curvature κ_0. The curvature at the free end $\kappa(0, t)$ relaxes to zero within the first few time steps (quick relaxation of the incompatible curvature near free end) while it is given in the intermediate regime (2) by the universal self-similar solution (4), shown in (b) as a function of $\xi = s/\sqrt{\gamma t}$. At later times, for $t \sim T$, reflections are generated from the clamped end $s = L$.

Viscosity versus pasta size

$$Q = \frac{\pi \rho \Delta P}{2^7 \eta l} D^4,$$

$$Q = \Delta M / \Delta t = \frac{1}{4} \pi \rho D^2 \Delta l / \Delta t$$

$$\frac{\Delta t}{\Delta l} = \frac{32}{\rho g} \left(\frac{\eta}{D^2} \right).$$

$$\tau_{\rm mix} \sim \left(\frac{\eta}{D^2} \right).$$