# Stat Mech (PHYS 370) Guide 3

Fall 2024 v1.2

We are getting our feet wet wading into the foundations of stat mech. Next week on Tuesday we have "calculus day", when we derive a bevy of results and Stirling's approximation. We'll apply these techniques to systems with high multiplicity states and then explore how this situation is related to temperature - and then discover what temperature is, fundamentally.

**Reading:** The book is very good. I highly recommend it!

On Thursday September 12 we discussed Chapter 2 sections 1-2 (and pages 60-61)

On Tuesday September 17 we will discuss Chapter 2 sections 3 - 4 and maybe Appendices B 1-3

On Thursday September 19 we will likely have a calculus day (Appendices B 1-3)

**Help Sessions:**

Office hours: Wednesday afternoons G052. There is also a chance you can catch me Monday morning. Email to see if I am available.

QSR drop in hours: Sunday 6 - 9 PM and Wednesday 7 - 9 PM

**Problems: (Due on Thursday September 19 at the start of class)**

(1) In the coin toss game discussed in class on Thursday September 12: There were two teams. Team One flips three fair coins. Team Two flips two fair coins. The team with the higher number of heads wins. If there is a tie then Team Two wins.

(a) Showing your reasoning, determine the probability that Team Two (with 2 coins) wins.

(b) What is the probability that Team One (with 3 coins) wins?

(c) Let's modify the rules a bit to account for multiple wins (again, inspired by the board game "Risk"). Let's assume each team both have a pile of things, say units of energy. The change in units is determined by pairs of coins where heads wins. It may be easiest to see how this works through examples: Consider the case when Team Two flips and finds HH and Team One flips anything at all then Team Two wins *two* units, one for each head flipped (recall that the ties go to Team Two). Now consider the case that Team One flips THH and Team Two flips HT then the result is a draw since each player wins one; no units are exchanged. As a final example, if Team One flips HHH and Player Two flips TT then Team One wins two. I hope the rules of this game are clear. If not, please ask! What is the probability that Team One wins two?

(d) Recall that the expectation value is defined by the sum of outcome times its probability over all outcomes, e.g. for states $s$

$$\langle q \rangle = \sum_s q_s P_s$$

where $q_s$ is the number of units exchanged. What is the expectation value of the number of wins for Team One?

(2) (1 - 4 pts.) This problem is on cooking pasta. For a minimal experience do part (a). Everyone should at least complete this part. For a maximal experience complete all parts. I am happy to provide a Kill-A-Watt meter for your measurements. Due to the wide range of experience this problem is worth between 1 and 4 points. You can turn in the later parts any time during the semester for possible bonus points.

  (a) The specific heat capacity of Hannaford's penne pasta is approximately 1.8 J/g °C . Suppose you add 350 g of penne at room temperature to 2 liters of boiling water. Suppose you turn off the heat and cover the pot and wait a bit, but not so long that the pot looses much heat to the room. What is the temperature of the water?
  (b) Usually pasta boxes and cookbooks recommend using a lot of water. For example, *Joy of Cooking* by Rombauer and Becker (1975) write, "...add pasta gradually to a large quantity of rapidly boiling water ... it is essential that the outer surfaces be penetrated as soon as possible, [requiring] ... about 7 quarts of rapidly boiling water for a pound of pasta. ... Timing can be gauged only by tasting not once by several times." Find the minimum energy required to heat 7 quarts of tap water to boiling. Estimate the total amount of energy for a specific type of stove (e.g. electrical, induction, natural gas, etc.)
  (c) Given the amount of pasta cooked in the world it makes sense to look more closely at this process. See the attached September 2023 National Geographic article. Can we use less energy to cook pasta well? According to America's Test Kitchen "...starches absorb water at 180°F ..." Estimate the amount of heat to cook 350 g pasta by adding the pasta to a minimum amount of boiling water so that the mixture remains at or above 180 °F . This should result in pasta that doesn't become 'gooey' or 'rubbery'.
  (d) Find the amount of energy required to cook 350 g of pasta for the Mia and Ross soaking method described in the article.
  (e) Reality: Try these methods - taste the pasta and record the amount of energy used. The easiest to record would be a plug-in electrical resistance heater with a Kill-A-Watt meter. But any burner of known power will work. Write up your observations including an analysis of the energy use and the quality of the resulting pasta.

(3) The HOC organizes a High Peaks Weekend with the goal to place a Hamilton person on all 46 high peaks in the Adirondacks. You plan to hike Mt. Marcy from the Loj. This hike is about 7 miles (one way) and an elevation gain of 3240 ft. (Thanks to Jan Wellford for the gain.)

  (a) Assuming a 13% efficiency of converting chemical energy from your breakfast to mechanical energy, and that all that work goes to climbing vertically. Roughly how many bowls of muesli (1 bowl = 374 kilocalories) should you eat before heading up Mt. Marcy? Please make any necessary measurements for your solution.
  (b) As we hike, about 3/4 of the energy of the muesli is converted to thermal energy. If there was no way to dissipate this energy how much would your temperature increase on the way up? Assume we are basically all water.
  (c) Of course this does not happen. (Hooray!) Fortunately, we have an efficient way to cool through the evaporation of water. How many liters of water should you drink to replace the evaporated water? At 25°C the specific latent heat of vaporization of water is about 580 cal/g. This rises with increasing temperature.

(4) 2.2 A relatively quick coin toss problem.

(5) 2.6 Multiplicity for a $q = 30$ and $N = 30$ Einstein solid.

(6) 2.8 Two Einstein solids

(7) 2.12 (Optional) Log review

IN THIS SECTION



ILLUMINATING THE MYSTERIES—AND WONDERS—ALL AROUND US EVERY DAY

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# Science, Boiled Down to Pasta

PUTTING PHYSICS TO WORK IN REAL LIFE CAN MAKE THE SCIENCE LESS INTIMIDATING, MORE DIGESTIBLE—PERHAPS EVEN INSPIRING.

BY **DAVID FAIRHURST**

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**OUR TASK WAS SIMPLE ENOUGH:** Find the most frugal way to cook pasta, and explain the science behind it.

But there was the Nobel laureate's plan to consider, as well as the opinions of Michelin-starred chefs. There were only a few elements—pot, water, pasta—but many ways to vary them, along with heat and time. There were ecological considerations, cost breakdowns—and, constantly, puns boiling over. All part of demonstrating science's real-world applications.

As often happens with scientific investigations, the inspiration came from something else entirely: a hummingbird hawk-moth using its slender proboscis to feed. As a physicist with a particular interest in all things soft or fluidlike, I was intrigued: How does the moth suck sticky nectar up that flexible tube?

So I challenged two students, Mia London and Ross Broadhurst, to scale up the problem using simple components. They chose bucatini, a long hollow pasta, and cunningly controlled its stiffness through cooking time. Success! They were indeed able to reproduce the conditions of proboscis drinking. End of story. Or so we all thought…

A few months later we were back in the lab, bubbling up more bucatini—because we'd plunged into a heated debate over the "best" way to cook pasta.

It began about a year ago, after Giorgio Parisi, a Nobel Prize–winning Italian physicist, shared architect Alessandro Busiri Vici's Facebook post on an economical way to cook their nation's favorite carb. Cut off the heat halfway through cooking and let the hot water finish the job, Busiri Vici advised. But "keep the cover always" on, Parisi emphasized, for insulation and to prevent heat loss from evaporation.

Even though energy and other living costs had soared in much of Europe, the thrifty suggestion Parisi and Busiri Vici shared stirred up angry responses from fellow Italians. "It's a disaster," raged renowned chef Luigi Pomata, admonishing that Parisi and other physicists should keep well away from the kitchen. Michelin-starred chef Antonello Colonna said customers in his restaurant would never tolerate the rubbery results of the recommended method.

But Colonna mentioned another cost-saving approach: the "cold water method," endorsed by American chef Alton Brown. Defying all culinary traditions, this starts with the pasta in cold water and brings everything to the boil together.

Others joined the social media frenzy, tossing in their opinions, insults, and recipes. Despite Nobel laureate Parisi's expertise—his theories uncover patterns in complex systems, from molecules to memory, from the flocking of birds to the spinning of planets—even he might not have predicted the reactions to his well-intentioned post.

**WHAT IS PASTA, IN SCIENTIFIC TERMS?** What happens when we cook dried pasta? And most important in the debate about the most delectable frugal-cooking techniques: Who's right?

The answer to question one is simple. Dried pasta is made by adding $H_2O$ to ground *durum,* a subspecies of *Triticum turgidum;* that is, by shaping and drying a mixture of water and semolina flour milled from durum wheat.

The answer to question number two: When we cook dried pasta, two processes take place, both pretty straightforward. First, it must rehydrate and soften by absorbing water. It does this by diffusion,

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the same principle as when perfume's scent spreads through a room. Driven by diffusion, boiling water molecules will penetrate to the center of a strand of typical-thickness spaghetti in about 10 minutes. Interestingly, diffusion slows down over time; in pasta twice the typical-spaghetti thickness, the water would take 40 minutes. This explains why you find chewy bits when strands get stuck together in the pot: There simply wasn't time for water to diffuse to the center of the clumps.

Second, the pasta must cook, which requires heat. Like the water, heat also diffuses into the pasta, swelling the proteins, breaking down starch grains, and making everything edible.

Online tutorials, package instructions, and ChatGPT generally agree on a standard method to cook pasta. Per serving: Drop three ounces of pasta into a quart of vigorously boiling water with a pinch of salt. Add oil, suggest some. Stir occasionally to stop sticking (or don't). Cook for around 10 minutes, enough time for both heat and water to wiggle their way in. Drain, rinse (or don't rinse). Add sauce (or don't). Serve.

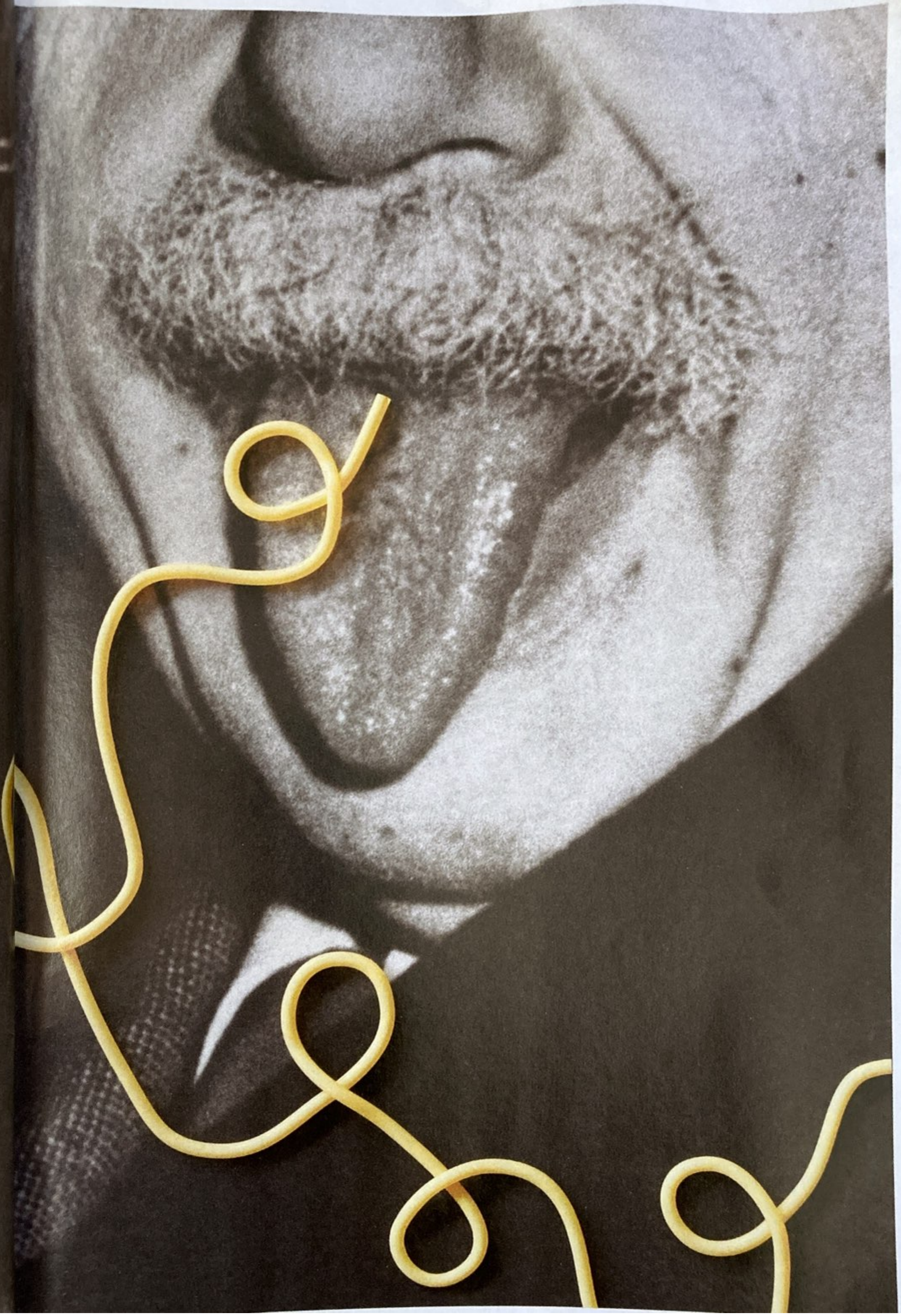
Minor changes in preparation may alter the taste but won't affect the cost of cooking, because it all boils down to the heating. The cost depends on how much energy is needed to heat the pot, water, and pasta to 212°F—and then, how much more energy is needed to keep it boiling for 10 minutes. To calculate precisely, we need to know the price of energy, whether you're using electricity or gas, and the type of stove; the metal the pot's made of, its thickness and weight, and the energy needed to heat it…

**YES, WE DID THE CALCULATIONS.** Mia, Ross, and I cooked pasta by the standard method, over and over.

## Consider the Pastabilities

One indisputable truth of the pasta-cooking experiment: It gave participants endless opportunities for puns and saucy wordplay. —DF

- **A fusilli puns**
- **Saving your pennes**
- **Orzo they say**
- **Pasta time away**
- **Using your noodle**
- **Penne pincher**
- **Pasta la vista**



We calculated the outcomes for various combinations of pot, stove, and energy source, and came up with an average cooking cost: about a dime a portion. Heating the water uses most of the energy; heating the pasta accounts for only one percent of it.

Across the United States, some six billion pounds of pasta are twirled and slurped every year, costing an estimated three billion dollars to cook. On a scale like that, even a small energy savings would make a big difference.

Let's review the possibilities.

Parisi and Busiri Vici's suggestion halves the energy used in the cooking stage and saves three of the 10 cents a portion. The cold water method of chef Brown also reduces the cooking stage, likewise saving around three cents.

Using less water will cut cooking costs too. Harold McGee, author of *On Food and Cooking*, encouraged *New York Times* readers years ago to try both a cold start and reducing the water to a third. He warned the approach "requires more attention" and regular stirring. But I reckon it would save some six of the 10 cents.

On *SeriousEats.com*, chef J. Kenji Lopez-Alt urges an even more dramatic method. He drops the pasta into minimal boiling water, stirs when it resumes boiling, then turns off the heat, covers the pot, and waits 10 minutes. Drain, eat—and save eight cents a portion, by my calculation.

Then Mia and Ross entered this culinary-science contest, and did not disappoint. They tried an alternative method—presoaking—whose success lies in separating the processes of rehydration and cooking. Though water diffusion is much slower at room temperature, after two hours the pasta becomes soft. Once drained, it can be heated briefly in a pot with water or sauce to finish cooking. By avoiding other methods' generation of steam that escapes and hot water that's thrown away—all wasted energy—this approach saves more than nine cents a portion. (The website of the Exploratorium, San Francisco's science museum, has an article, a recipe, and a video about the method.)

You might legitimately ask: Why are university scientists perfecting the cooking of pasta? Or the blowing of soap bubbles (see adjacent column)? Have they not heard about the threat of climate change or the challenges of sustainable energy production? Yes, we have. But to tackle these global issues requires a wider diversity of scientific voices and the support of a public that is both curious about the discoveries of science and trusting in its processes.

By lifting the lid on the science of everyday life, we hope to prepare many others to thrive in an increasingly technological world—and to use their awareness and passion to protect the planet. □

**David Fairhurst** is an associate professor at Nottingham Trent University, England, where he investigates flow and evaporation in blood, bubbles, droplets, and puddles. He teaches general relativity and science communication, and runs the postgraduate program.

## More real-world science ventures

In addition to the pasta-cooking experiments, David Fairhurst has joined colleagues and students at Nottingham Trent University in numerous other studies of everyday, close-to-home science. Among the phenomena they've explored:

- The ideal technique for blowing the biggest soap bubbles. During a science interactive at Nottingham Castle, university scientists asked members of the public to blow bubbles while the scientists recorded the speed of breaths blown at the soap film and the size of the bubbles formed. The conclusion: Blowing at a steady airspeed of around 24 or 25 feet a second regularly produced bubbles "up to 10 times the size" of the wand, Fairhurst says. Blow slower, and the bubbles won't detach from the wand; faster, and they'll burst before getting really large.
- The physical process that occurs when a liquid droplet is left to dry on a solid surface; in particular, how it's affected by gravity. Understanding the evaporation process has implications for a wide range of processes, from crop spraying to virus transmission. Another droplet study recruited volunteers to exercise, then examined dried drops of their blood drawn before and after exertion, noting how patterns differed between resting and exhausted states. The approach shows promise for monitoring health and screening for diseases. —PATRICIA EDMONDS