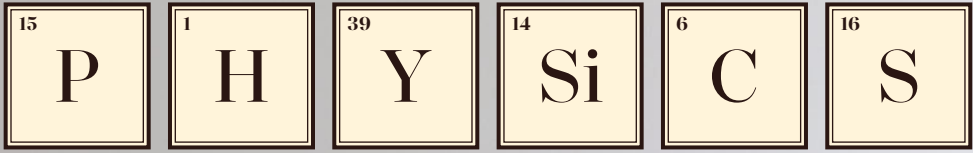


GEORGE VEKINIS



IN THE
KITCHEN



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George Vekinis

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About the Author

George Vekinis is a research director and the former head of the Education Office at the National Centre for Scientific Research “Demokritos” in Athens, Greece, and a university lecturer on advanced materials and technological entrepreneurship. He earned a Ph.D. in Physics at the University of the Witwatersrand in South Africa and an M.B.A. (Core) at the Open University, UK. In the past he worked at universities in South Africa and the UK (University of Cambridge) and has served on numerous scientific and technical committees. He has traveled extensively, supervised the research work of over 120 students, and published and lectured extensively on physics, space exploration, materials science and engineering as well as technology transfer and entrepreneurship. His work has been funded by the European Commission, the European Space Agency as well as various industrial entities, and he is the author of two books on entrepreneurship and technology commercialization. He is happily married in Athens with two grown children and two three-legged rescue cats. At weekends, he can reliably be found cooking up a storm in the kitchen.



1

Introduction



"Explore the world. Nearly everything is really interesting if you go into it deeply enough."

Richard P. Feynman

A Physicist Cook's Welcome

The laws of physics are everywhere—from the way we think and breathe and walk to the way our devices operate, and from the way our food is cooked to the way we eat it and get sustenance from it. They are so ubiquitous and all pervasive that they are invisible. We have grown up so immersed in them that we don't even consider them or think about them as we go about our business under their total control. They are hidden in plain sight. Nearly everything happens in nature—the kitchen included of course—according to a plethora of unchanging rules (that's why we call them “laws”), discovered and clarified over many years by thousands of patient and persevering scientists. They are the rules according to which the Earth moves, plants grow, and we stay alive. Ok, we don't yet completely understand everything, but give us time... every day thousands of scientists are working towards a better and better understanding of nature at all levels. From its workings at the atomic and sub-atomic levels right up to the Universe as a whole and its origin. We think up theories and hypotheses and then carry out systematic experiments and careful observations to confirm them or discard them. And we are guided by them in our everyday lives, mostly without realising it.

That's what this book is all about. I'm a research physicist and at the same time I love cooking and experimenting with new combinations of foods, aiming to make interesting meals and cakes in the kitchen. But most of all I love observing the physical phenomena that occur while I'm doing the cooking and seeing how they affect the results. While I'm at it, I make mental notes about how things proceed and may make adjustments or try new ideas depending on what the physics—and the results of my experiments—tell me. It's the scientific method in the kitchen. I don't always succeed in making a gourmet supper, but the physics I see and the experiments I try are definitely exciting! And sometimes it happens that the details of certain phenomena we see in the kitchen are not what we expect or have come to believe.

I do the same in my scientific research. I observe what happens during and after making specific adjustments in my experiments, and the feedback I get guides my next steps. At the same time, I keep an open mind for corrections or even additions to my knowledge. Whereas most of the basic laws of physics are well understood and have been confirmed thousands of times, some lesser phenomena are still under investigation and their meaning is still being debated. And if we find that an existing theory is not completely correct, we are the first to correct it or even discard it. That's how scientific study works. By checking again and again, by going to sleep with questions and waking up with new ideas to test in order to answer them. I often do the

same with cooking. If something doesn't work as I hope, I adjust it or change it.

In fact, if I may digress a bit, that's how the two greatest discoveries of modern physics were made. Struggling to account for certain "annoying" experimental and observational discrepancies that couldn't be explained with the knowledge of that time, the great scientists of the beginning of the twentieth century discovered the two greatest fields of modern physics: quantum mechanics¹ and the modern theory of gravitation (the general theory of relativity).² The first gave us a clearer picture of the atomic world, and it also gave us electronics, computers, and a myriad other technological marvels that we can now hardly imagine living without (including in the kitchen), while the second gave us a much better understanding of the birth, development and dynamics of the Universe and all the stars and other bodies within it.

But enough digression. Let's go back to the kitchen and the physics that abounds in it. All the phenomena that we observe while cooking obey the laws of physics, as does everything that happens around the kitchen obey the laws of physics. Actually, everything obeys the laws of physics, at least on this Earth, and we believe everywhere else in the universe too. This little book is an attempt to point out and clarify a few of these laws that govern our everyday lives. And what better place to search for and observe them than in our pots and pans and the various devices we keep in our own kitchen. I wrote it because I love observing how ingredients (themselves made by and governed by the laws of physics) heat and mix and combine to make a meal that will in turn (hopefully) excite and please our brain via what else but our physics-obeying taste buds, smell sensors, eyes, and even ears.

The modern kitchen is an exciting place. It's full of devices, gadgets, and machines created for our benefit. It's the nexus of so many of our daily activities that the mind boggles when we start considering them all. It's where energy, water, and raw materials meet and are tamed by our own energy and ingenuity to create food for our pleasure and sustenance. And it's where we exploit and use—usually unknowingly—a whole range of the laws of physics.

Consider something as simple as water coming out of a tap. How does that happen? There is a fundamental law of physics that says that any system if left alone will always try to reduce its internal energy.³ Because the water

¹ Ludwig Boltzmann, Max Planck, and Albert Einstein to begin with, followed by Niels Bohr, Louis de Broglie, Max Born, Paul Dirac, Werner Heisenberg, Wolfgang Pauli, Erwin Schrödinger, and later, Richard Feynman. And many others too.

² Albert Einstein, single-handedly.

³ In thermodynamics, we'll see later, there is an equivalent law for heat (the "second law") which says that heat can only flow from a place of high to a place of low temperature. If you want to reverse the flow, you have to input energy.

in the pipe is under a high pressure (about 6 times atmospheric pressure and the poor old pipes are straining to contain it, sometimes failing by rupture or leakage), it contains a large amount of energy. As soon as the tap is opened, water gushes out, because this way the energy of the system (the pipe and the water in it) is reduced. The water we see gushing out is pushed out by the water behind it, which is still under pressure in the pipe. Just like a mass of people pushing to go through a narrow gate into a stadium. As soon as you get through the gate, you feel the pressure behind you decreasing and you are free. The same happens in the water pipe. As soon as the water emerges, it is free and its pressure drops to that of the surroundings. Of course, it is immediately acted upon by gravity, which forces it downwards. If there wasn't any gravity, it would just dance around aimlessly, splashing about, happy to be free.

And, guess what. Exactly the same principle governs the movement of electrons through a wire. There is a force pushing them forward (we call it the “potential difference” or voltage) which forces a few electrons at a time⁴ out of the end of the wire and into the electric circuit it is connected to, where its charge (negative, by convention) is used as a unit of energy to carry out some work.

Every time I cook, I enjoy seeing how many physical phenomena are involved in preparing a simple meal or just a cup of tea. Even a simple action in the kitchen such as boiling water in a kettle utilizes many physical phenomena and laws of physics. First, operating the switch forces two pieces of metal (copper) to touch by exerting a force on them which closes an electric circuit. This allows electrons to flow (again in order to minimize the energy of the system) through the wires to the kettle, heating the element, which is made of a material that resists electron flow. This resistance to electrons (something like friction—rub your hands together vigorously and see how they heat up) makes the element heat up. The element then passes (“conducts”) the heat to the metallic base of the kettle and from there to the water above it. The water molecules begin to vibrate more and more violently till they can't take it any longer and start escaping as steam!

Read the above paragraph again and count how many physics laws are involved just to boil water! Our finger exerts a force on the switch which snaps shut. Both these actions involve forces which distort the materials involved: our finger (via our muscles) and the switch materials. Such mechanical distortions obey, and are described by the physical laws of elasticity. Electrons “jumping across” the touching metals obey the laws of quantum mechanics,

⁴ Well, hardly a few ... maybe a few trillions per second, depending on the application. If it's for heating, it's actually a heck of a lot—see later.

while electrons flowing around an electric circuit do so according to the laws of electricity. When we heat the element and when we heat the water which boils and evaporates, what happens obeys the laws of thermodynamics. Physics is indeed everywhere.

But Wait—Is It Physics or Chemistry in the Kitchen?

When I was writing this book, I (often) had to answer the question “but isn’t cooking more to do with chemistry than with physics?” Well, I admit it’s a good question and it’s a good idea to clarify it at the outset. Chemistry deals with the properties of molecules, especially when they react together to give something different, like a solution or another compound. But physics explains *how* such reactions and interactions take place. In this respect all chemical processes obey and are underpinned by physical laws, and specifically the rules of quantum mechanics. In the case of chemical reactions, chemistry tells us what is taking place, while physics explains why and how it’s taking place. To a good approximation chemistry describes the results of interactions between electron “orbitals” which are defined by quantum mechanics. These “orbitals” have nothing to do with orbits, but are just regions where electrons can be found around atoms. Depending on which orbitals they belong to, the electrons have different, distinct energies. Actually, the word “quantum” (“packet” in Latin) was coined because the energy of each orbital is always some multiple of a very small increment of energy.

Before we go on, I think we need a clarification about chemical bonds and I’ll try to keep it simple. All organic molecules, including the proteins, sugars, and everything else we use as food, are made up of atoms which are bonded together in some way. There are many types of bonds in organic materials, but the basic ones that concern us here are “covalent bonds” made by “sharing electrons” (or, more correctly, “interactions between electron orbitals”), which can be moderately to very strong, “ionic” bonds which rely on electrostatic attraction between positive and negative ions (atoms) and “hydrogen bonds,” which involve hydrogen atoms and are much weaker. Hydrogen bonds are very widespread in organic materials like foods and a special type of them is often found in small volatile aromatic molecules of herbs, coffee, tea, etc. Moderate strength covalent bonds generally occur between smaller satellite molecules and a main strong core molecule in proteins and other similar structures, as well as between the amino acids that make up the long protein molecules. However, amino acids and other basic molecules always have a

backbone made up of carbon atoms which are held together by strong covalent bonds. During cooking, as we increase the total energy input (increasing temperature and time), the hydrogen bonds break up (“dissociate”) first, followed by the moderate covalent bonds, and only at high temperatures (that we usually avoid in cooking) do the backbone carbon molecules break up.

Very often, as soon as some bonds break up, new ones form. When a “solute” molecule dissolves in a “solvent” liquid, the solute molecule breaks up and forms new bonds with the solvent molecule.

A lot of chemistry takes place during cooking, but cooking is much more than reactions (or interactions) between molecules. While chemical reactions do take place when we mix and heat ingredients, it is the laws of physics (heat distribution, electrical interactions, orbital interactions, diffusion, etc.) that hold sway over everything that happens in the pot, and in the kitchen in general. From the moment you put a pot on the stove to the moment you pour out a drink and swallow your food, you are, often without thinking about it, exploiting or obeying physical laws.

In fact, when cooking, we often try to avoid chemical reactions. While we exploit and use chemical solutions and try to “brown” certain foods, more often than not we try to preserve many of the properties (the aroma, the taste, the structure) of the raw materials we put in, and try to blend them and find a balance between them which will provide culinary pleasure. In some cases, we do encourage (and control) certain chemical reactions during cooking, such as a slight “caramelisation” when stir frying of onions or leeks, which slightly alters their taste, aroma, and structure. Or we use an acid or the protein of an egg to encourage lipids (fats and oils) to stick to water. Furthermore, one of the pillars of a sumptuous meal, a smooth sauce, does involve chemistry which, in actual fact, is the same chemistry that we use to make plastics: polymerisation reactions. We’ll discuss these aspects later and delve more deeply into the corresponding mechanisms in order to understand the physical processes that make them happen.

In a nutshell, this is the main objective of this book. To delve into, wonder at, and elucidate many apparently simple phenomena that occur in the kitchen, things that we usually take for granted. Through numerous examples, I’ll try to show you some of the physical phenomena and laws that hide behind what happens in the kitchen, and show how they actually arise. Along the way I hope to be able to give you a fresh perspective on one of the most satisfying human inventions and pursuits, cooking. If you are, like me, an eternally inquisitive type of person and an aspiring and curious cook (forever experimenting, sometimes to the consternation of my family), I hope you’ll

enjoy the never-ending cascade of wonderful insights that we can get on the way to making that lovely casserole.

A Few Words on the Structure of the Book

In an attempt to ensure some logical sequence and a good physics grounding on the basic concepts (which I'll refer to throughout the book), I have started with an introduction to energy and the laws of “thermodynamics”, the science of heat. Many readers may already have a good basic understanding of such matters, and I beg your indulgence. In any case, I'll take you on a brief journey of the basics of energy—the basis and currency of everything—and how it is used in the kitchen, mainly in the form of heat and electricity. We'll look at how energy originates and how it gets transformed all the way from the power station until it becomes heat in the kitchen, where some of it is used to cook and some of it is lost to the environment.

Once we have established the basics of heat energy, we'll consider physical aspects of the basic ingredients that go into cooking, starting with the amazing properties of water. We'll look at coffee and tea, the colours of foods, and lots of other unusual aspects of the raw ingredients.

Next, we'll consider the physics and chemistry that goes on in the pot, the frying pan, the oven, and anywhere else where our raw ingredients can be turned into a hopefully palatable meal. This will form the main part of the book and it will include examples of actual cooking which, I hope, will help you see food preparation with a fresh eye and even surprise you in some ways. Here I discuss various cooking tasks, in some detail at times, and describe how stews, sauces, fries, and roasts take on their colour, aroma, and taste. I have attempted to incorporate cooking methods from various parts of the world but, being Greek myself, I have mainly focussed my discussion on Eastern Mediterranean cooking. By the way, I have only used examples and descriptions of foods using natural ingredients and do not discuss any of the numerous artificial agents used for producing ready-made meals, such as artificial emulsifiers, acidification agents, and all the chemistry that goes into making nice-looking and tasty, but hardly natural (or naturally nutritious) food.

Next, we'll look at many of the ubiquitous kitchen appliances, devices, machines, and materials in a modern kitchen. There will be quite a few further surprises there too. By necessity, some of the discussions here may duplicate certain comments I made during the cooking chapters, but they are based on a more technical viewpoint.

Finally, we'll talk about various miscellaneous subjects and odd aspects of cooking and working in the kitchen that don't fit anywhere else, but are nevertheless intriguing and surprising as well.

Nearly all the chapters can be read individually and in a random order, but I think they'll be more satisfactory if you read them approximately in the order presented. If you have a good grounding in physics, then you could skip the first part on energy, thermodynamics, diffusion, etc. However, if you persevere with it, you may also be surprised at certain nuances that are often forgotten or taken for granted.

I should mention that experienced cooks and chefs may find some of my descriptions of cooking processes too simplistic, so I hasten to emphasise that the book is not meant to be a treatise on the methods of cookery, but an attempt to elucidate the underlying physics.

Because many of the physical phenomena I discuss occur again and again in various situations in the kitchen (and especially in cooking), it has been necessary sometimes to repeat certain descriptions, but to avoid tiring the reader, I always try to emphasise the extra dimensions that come into play in each situation, so please bear with me.

Before I proceed, I must ask forgiveness from scientists and purists for the frequent over-simplifications I have used in order to make my explanations of physical phenomena a bit easier and clearer. I have done this in an effort to avoid confusion and jargon. To atone for this, I have included more precise explanations, related aspects, and other interesting bits of information in footnotes and information boxes, where I thought it would enable a deeper understanding and complement the points made in the text. In addition, I have left out nearly all the equations describing the phenomena I discuss, once again to avoid confusion and concentrate only on the physics. In some cases, this means that I only mention and briefly describe the relevant law without going much deeper.

Obviously, I have not attempted to include or discuss in any detail advanced phenomena such as energy perturbations or waves or certain quantum mechanical effects which may occur during cooking and elsewhere in the kitchen, apart from stating them. This is simply because they are too complicated and in any case wouldn't add much to the discussions of the main physical phenomena we encounter when cooking. If anyone wishes to dig deeper, I suggest they consult one of the many good textbooks on physics.

During the preparation and writing of the book I had the pleasure of receiving and discussing many ideas and tips from my wife Gwen and my children Andrew and Stefani, and I thank them for those gems. I especially

enjoyed the many heated discussions on what is worth including and how to go about it.

Finally, I want to stress that all the things I have written and discussed in this book are my own opinions and interpretations of the physical phenomena that occur in the kitchen, some of them perhaps not uncontroversial, and I have done so to the best of my understanding and ability based on publicly available knowledge. It goes without saying that everything I have written is my responsibility and mine alone.

So, without further delay, let's enter the world of physics in the kitchen. And the very first item on the menu and the most salient characteristic of all our activities in the kitchen is the fact that everything is driven by energy.



2

Building an Appetite—Energy: The Currency of Life, Food, and ... Everything Else



“Everything is energy”

Albert Einstein

What is energy? In everyday parlance we understand it as something that gives us the ability to do something: walk, run, heat, dig, breath, cook, blow air, remove air, work on a laptop, etc. It's actually not a bad definition and quite close to the more or less official definition: "Energy is the basic physical entity that enables a system to do useful work". A system could be a machine, a person, or a device of any type. And work means any action whether it has a purpose or not. Usually, we cannot observe energy directly, but we can infer its presence by observing the work that it enables. Nobody and nothing can do any work and nothing can be produced without some energy input that allows it to happen. So, we can say that energy is the currency of life. A limited amount of energy means limited ability to do something and vice versa. Objects which have a lot of energy (either because they are given or produce it) are able to do a lot of work and to carry out more actions. In general, every action everywhere depends on the availability and sharing of energy by the objects that are involved in the action.

Joule: the man and the unit of energy

We measure energy in joules (J) from the nineteenth century English physicist James Prescott Joule who showed that all types of energy (mechanical, electrical, chemical, gravitational, etc.) are basically the same and can be converted from one to another.

A joule is a very small amount of energy, just enough to lift your arm about 10 cm, to light an LED for 1 s, or to lift an apple by one metre. Everyday tasks require thousands or millions of joules of energy. Sleeping for just one minute requires about 6000 J while heating a couple of cups of water in the kettle to boiling temperature uses about 200,000 J! And cooking a meal in a pot might use more than 2 million J!

But what exactly is "work"? There are many ways of defining it, but I like the following: "Work is any process or activity by which something is created or produced or just happens". In the kitchen, energy input enables work to be done so that a kettle can heat water for tea, or you can cut up the ingredients of a salad, or an oven can broil a steak, or a toaster can toast a sandwich. Work enabled by electrical energy may also produce light from a bulb or music from a radio or warmth from a heater.

If energy is the currency of life, work is the tool you get by paying in energy. And in cooking, work is necessary to produce all the intermediate stages as well as the final product. Think about it: when you make a soup or a stew, you pay in energy to prepare ingredients, heat up the hob, and boil

water. You also pay in energy to get your mouth to swallow food and to get your stomach and digestive system to work on digesting a meal.

So, energy is used to enable work to produce something. That gives us another angle by which to understand energy and work better. Since, in order to produce something, you have to put some effort into it, the amount of work you need to do is directly related to the amount of effort you need to make. It's also directly related to the spatial extent and the time over which you make that effort. Let's say you need to cut a large piece of hard cheese with a knife. The harder the cheese, the more force you have to exert and the more tired you'll feel because you have expended a lot of energy. But you'll also expend a lot of energy if you have to cut a softer but larger cheese, which will take you longer to cut. In physics, energy is actually measured just like this. If we measure the force and the total distance over which it acts, then the work done and the energy expended are given simply by the product of the force and the distance.

Let's look at another example of work in the kitchen. Making béchamel sauce involves beating (whisking) the butter, flour, and milk mixture over a warm hob (or warm water) for a long time until it thickens. The work you put in is paid for by energy produced in your body and by the hob. The longer you beat the ingredients, the more energy you expend, and the more you can feel the energy being depleted in your muscles, where sugar is slowly converted to lactic acid, giving you that feeling of tiredness. That energy originally comes from metabolism of food, which converts it into usable energy sources like sugar and fat. But only a small proportion of that energy is available for beating the béchamel. As you work, your body still has to expend energy to keep you at the right temperature, to keep your heart and other organs working, to ensure you remain standing and keeping your balance, and to keep your brain thinking about how to move your hand, estimate quantities, prepare the next steps, and so on.

There is no free lunch. We need to provide energy to a system to get it to produce work, but where does this energy come from? In everyday life, and certainly in the kitchen, the energy we use for cooking is available in two forms: electricity and gas for producing a heating flame. Both are used to create heat for cooking, whereas electricity can do many more types of work, such as light the room, beat a cake mixture, squeeze an orange, remove heat from the fridge, cool the room, wash the dishes, or move the air in the oven. Our body is also a system that does work and our energy comes from burning food inside us to produce energy to drive muscles, nerves, and much more.