Indian Journal of Experimental Biology
Vol 46, May 2008, pp. 389-394

Mode coupling in living systems: Implications for biology and medicine

John Swain
Department of Physics, Northeastern University, 110 Forsyth Street, Boston, MA 02115, USA
and
International Institute of Biophysics (IIB), Landesstiftung Hombroich, Raketenstation, D-41472 Neuss, Germany

Complex systems, and in particular biological ones, are characterized by large numbers of oscillations of widely differing frequencies. Various prejudices tend to lead to the assumption that such oscillators should generically be very weakly interacting. This paper reviews the basic ideas of linearity and nonlinearity as seen by a physicist, but with a view to biological systems. In particular, it is argued that large couplings between different oscillators of disparate frequencies are common, being present even in rather simple systems which are well-known in physics, although this issue is often glossed over. This suggests new experiments and investigations, as well as new approaches to therapies and human-environment interactions which, without the concepts described here, may otherwise seem unlikely to be interesting. The style of the paper is conversational with a minimum of mathematics, and no attempt at a complete list of references.

Keywords: Biophoton, Biological oscillation, Mode coupling, Nonlinearity, Non-material medicine

Introduction

It is well-known that coupled oscillators of *similar* frequencies will, under a wide variety of conditions, tend to become synchronized. This paper addresses a related but distinct issue which is the coupling of oscillators of *very different* frequencies – something which is often imagined to be a very weak, despite the fact that it is easy to find extremely large effects in very simple systems encountered every day.

Biological systems exhibit periodic behaviours with time scales that cover many orders of magnitudes. Some of the oscillators which are present in a living thing may be periodic over a year (hibernation, migration, annual growth cycles of trees in places with seasons, etc.), over a day (the usual circadian rhythms), over a few seconds (breathing), over about a second (human heartbeats), over a tenth of a second (electrical activity of the brain), over thousandths of a second (acoustic vibrations corresponding to voice), *etc.* all the way down to the very short time scales associated with the excitation of oscillators of the electromagnetic field including infrared and visible light which have time scales many, many orders of magnitude shorter.

Telephone: +1 617 372 2951
Fax: +1 617 373 2943
E-mail: john.swain@cern.ch

It is the basic idea of Fourier analysis that, subject to a few technical assumptions, and function can be represented as a sum of waves of various frequencies and phases. This is more than just math, as one can readily notice any time one hears the radio noise produced by a flash of lightning— a sharp pulse in time contains many frequencies including high frequencies which show up in an AM radio as radio waves. In a similar way to the way that a lightning strike is made up of many frequencies, can one think of a living thing as made of many oscillators?

One may argue that the oscillations of a biological system are of various different kinds. Some are mechanical (like heartbeats), some are chemical (circadian rhythms), some are of electric currents (brain waves), some are of the electromagnetic field (heat) and some are acoustic (voice). The objection is valid to some extent, but at the most fundamental level all these interactions are electromagnetic in nature. At present we know of four fundamental interactions. Two are nuclear forces of such short range (about the size of an atomic nucleus) that one can largely ignore them for almost every biological process (though I'll return to this issue a little later). Gravitational forces are very weak in the biological systems we know on earth and can be largely neglected. The remaining force is the electromagnetic one, and ultimately governs all the phenomena we think of as “mechanical”, “acoustic”, etc.

Why then do we think in terms of “mechanical” oscillations or “acoustic” ones as if they were not electromagnetic? Essentially this is just a matter of convenience. Rather than keeping track of a large number of microscopic degrees of freedom (charged particles and photons), we “lump” them together into coarser degrees of freedom which are macroscopically recognizable as “vibrations” or “sound waves”. This “lumping together” brings us to the important concepts of linearity and non-linearity, to which we now dedicate some more attention in detail.

Linearity and non-linearity

Let us review the mathematical definition of linearity. A function h(x) is said to be “linear” if it satisfies two requirements:

$$h(x+y) = h(x) + h(y)$$
$$h(bx) = bh(x)$$

The first requirement says that a linear function of a sum of two quantities is the sum of the functions of each quantity. For example, if h(x) gives the height of a water wave as a function of some disturbance x, then sum x+y of two disturbances x and y will give rise to a wave of the height h(x+y) which is the sum of that which would be due to x (i.e. h(x)) and due to y (i.e. h(y)). The second equation is similar and says, for a constant b, that “b times the disturbance will give a wave b times as high”.

Linearity represents a degree of separability—that is, it says that there are no synergistic effects between causes x and y, and that the response of a system described by a linear function h is simply the sum of the responses to individual causes.

Linearity is always an approximation. Keeping to the example of water waves, there is a critical height for a water wave such that it will topple over (think of waves breaking on a shore). Consider now a disturbance which would make a wave ¾ of the height required for a wave to break. Two such disturbances would *not* produce a wave 2×3/4=1.5 times the height which would correspond to a breaking wave—the wave will break! The effects of each disturbance cannot simply be calculated from the results of smaller disturbances. A new phenomenon—the breaking wave—arises.

Keeping to the concrete example above, how would one think about this in terms of Fourier series? We didn’t say anything about frequencies of the waves, but for the sake of definiteness, let’s say the small waves were of frequency f. The breaking wave is clearly not the sum of a lot of waves of frequency f (that would be just one more wave also of frequency f and would represent linearity of h) —it would need to be represented by a large number of frequencies including very high frequencies (short wavelengths) which would be needed to represent the short wavelength fluctuations corresponding to the “white water” of the breaking crest.

What lessons can we draw from this example? One is that driving a nonlinear system at frequency f can give rise to excitations (waves in this case) of frequencies different (and perhaps much different) from f. The other is that collections of excitations of various frequencies can be usefully described as a single excitation of a well-defined frequency, with some detail left out. In this case, “breaking waves” is a useful collective concept even though breaking waves are not sinusoidal, and thinking of them as waves of a well-defined frequency necessitates leaving out a lot of the interesting details (i.e. the froth near the breaking point).

Simple examples from physics

The mathematical assumption of linearity is extremely convenient from a calculational point of view. It underpins the usefulness of Fourier analysis: any disturbance can be broken into a sum of simple sinusoidal waves, and if the response of a system is linear, and one knows how it responds to such waves, then one can calculate its response to any disturbance by adding up the (known) responses to the waves that make up the disturbance. It also underpins the related approach of Green’s functions, where one breaks up a disturbance into a sum of sharp impulses (think of “knocks of a hammer”) of various strengths. If one knows the response of a system to a sharp knock of any given strength, linearity allows one to compute its response to any sum of arbitrarily hard knocks – that is, to an arbitrary disturbance.

The problem with linearity is that it implies a certain sort of triviality. Let us consider what may be a startling example since it is so commonplace—the spectrum of radiation from a hot ideal absorptive body (“blackbody radiation”). In concrete terms, think of the hot filament of a light bulb.

The usual way that a textbook calculation goes roughly (following the original derivation by Planck, but simplified for this discussion) as follows. Replace the hot filament with a box with reflective walls in which electromagnetic radiation can be present. For each mode of oscillation of the box (each way a wave can "fit" in the box) associate an oscillator with the frequency corresponding to that mode. Recalling that frequency f and wavelength L are related to the speed of light c by c=fL, there will be a longest wavelength (lowest frequency) that can fit. Waves of arbitrarily high frequency (short wavelength) will fit in the box. How does one figure out how much of each frequency is present in the box?

The assumption one makes is that one should maximize the number of ways to distribute an energy E supposed to be in the box among the oscillators. This is supposed to be the most probable macroscopic state (the state of "maxium entropy") in which to find the radiation in the box. The solution is immediate: if all oscillators are equally easy to excite, one would find a flat spectrum, and with an arbitrarily large number of oscillators of arbitrarily high frequency, one would find all the energy in oscillators of arbitrarily high frequency – the so-called "ultraviolet catastrophe". Planck's solution was to associate an energy hf with each oscillator of frequency f (where h is "Planck's constant") in order to make it more and more difficult to excite higher and higher frequency oscillators. This tradeoff between maximizing entropy ("put the excitations into lots of modes") and the cost of exciting higher frequencies ("put the energy into the lower frequency modes") gives rise to the characteristic black body spectrum, going to zero as frequencies go to zero and infinity, with a peak which rises with the total energy present in the box.

All this is completely standard, but let us revisit the argument a little more carefully. The oscillators representing the electromagnetic field were all considered to be independent – they represented distinct modes for the box, and were uncoupled. For example, any number of red excitations in any direction will be unaffected by, and unable to affect, any number of blue excitations in any other (or even the same) direction. These assumptions are needed even to be able to add the energies of the oscillators together in order to get them to sum to the total energy E (*i.e.* we assume that there are no interaction energies). But since the oscillators are assumed not to interact, how does the total excitation energy get redistributed among the various oscillators in order to maximize entropy? Clearly something is inconsistent – for part of the derivation one assumes that the oscillators are independent, but in order to transfer energy between oscillators of different frequencies we need to couple them. Furthermore that coupling must be nonlinear or else it cannot mix different frequencies.

Let us look in even more detail at the problem of a hot filament of a light bulb, say connected to a DC current source such as a battery, providing a potential difference of 1.5V (i.e. a flashlight). The output frequencies include oscillations at frequencies of around a million billion Hertz, corresponding to visible light, and energies (E=hf) of several electron volts. What are the input frequencies? The battery is at zero Hz – about as low as one could imagine going! The electrons passing through the filament have energies of 1.5eV maximum from the battery, releasing it in many collisions with the filament material, each depositing a tiny fraction of an electron volt. All the input excitations then carry energies and frequencies much, much smaller than those associated with the visible (or even infrared) output of the hot filament. In other words, the filament acts as a highly efficient mode coupling device, coupling oscillators of widely differing frequencies.

The foregoing argument applies to any filament that gets hot enough – no special geometry is required.

To make clear how common and large mode-couplings can be in condensed matter, let us examine another textbook situation, also not appreciated from this point of view. Consider a coil of wire of inductance L and resistance R. Connect across that coil a neon lamp – a small glass bulb filled with neon gas with two electrodes which allow a spark to pass when the voltage between them increases to about 100 V.

Now if this combination of coil and neon lamp in parallel is connected across a small battery (of well under 100 V – it could be 9V, say), nothing interesting would seem to happen. Certainly the bulb will not light up. What will happen is that current will build up in the coil with an associated magnetic field around the coil, with a maximum current set by the resistance R and the battery voltage, in accord with Ohm's law. If the battery is now disconnected suddenly, an electromotive force U will appear across the coil given by

$$U = -L\frac{dI}{dt}$$

where dI/dt is the rate of change of the current in the coil (again being determined in part by the resistance R). For large enough values of inductance L and small enough values of resistance, this U can be orders of magnitude higher than the battery voltage and easily enough to light up the neon bulb. Here again we see a simple example of mode coupling. Each electron that makes up the current in the coil carries a maximum energy of at most what it would get from the battery, and if the situation were linear, U could never exceed the battery voltage. The coil, simple as it is, enables the coupling of many low energy (again, low frequency by E=hf) modes into a higher energy one.

Of additional interest is that this same mechanism is basically that which may be at work in nuclear transmutations which have long been known to occur in exploding wires (see ref. 1—although that work does not take the engineering perspective described here, the basic idea of collective interactions of large numbers of low energy electrons to produce high energy ones is essentially the same.). It may be of interest given the fact that we know such large up-conversions (couplings of many low energy modes into a high energy one) can occur, to revisit old claims that biological systems may perform low energy nuclear transmutations. In place of large inductances, one may imagine biological ferroelectrics playing a role.

Thus we have seen two systems, one thermal and one not, which are capable of coupling oscillators of widely disparate frequencies. If a simple light bulb filament or a coil of wire can enable these sorts of mode coupling, what may one expect in the richly structured matter that comprises living systems?

Implications for biology and medicine

In an earlier work[2] I had argued that a specific large mode-coupling mechanism could very efficiently couple many (around 400) microwave photons stored as coherent Fröhlich oscillations into single coherent excitations in the visible region of the spectrum (the biophotons of coherent ultraweak bioluminescence). In particular, I argued that one could experimentally test that particular suggestion via looking for changes in Fröhlich microwave oscillations in response to visible light excitation and changes in biophoton emission via microwave oscillations.

In this paper I would like to make a more general argument for large mode couplings. As argued earlier, a living organism comprises a wide variety of *nonlinearly coupled* (not independent) oscillators. While it is often convenient to think of one or another oscillator as independent (much as it was convenient for the derivation of the Planckian blackbody spectrum to at times think of the field oscillators as uncoupled), they are all interlinked. That is to say, changing any one can change all the others.

A few simple examples are in order here before moving on. Consider the effect on the body of changing one oscillator – the rate of breathing. It is well known that if the breathing is made slow and regular, this leads to a slowing and regularization of heartbeat – another oscillator. This can also lead to changes in brainwaves associated with relaxation. This is all pretty well-known, though more in the East via traditions such as yoga, qi-gong, and other meditative practices) than in the West which tends to compartmentalize bodily functions (and disorders). More sophisticated changes of that one oscillator – the breath – can have a variety of physiological effects and the point I want to make here is that this should not come as a big surprise. Here the time scales involved are from 0.1 Hz (1 breath every 10 seconds) to 10 Hz (brainwave frequencies), representing mode couplings over two orders of magnitude – and again, that this occurs is a simple experimental fact.

I'd like to give another example[3] which although anecdotal, is suggestive. The story, if I recall correctly, was of someone with cancer (arguably in a sense a defect in the division and apoptosis rates of cells – another defective oscillator!) who was told to make a point of getting up with sunrise each day and go to sleep at sunset. That simple driving of one biological clock at a well-defined and regular frequency (linked of course to the natural phenomenon of sunrise and sunset) apparently resulted in a remarkable improvement of the patient's condition. While I cannot claim reproducibility of this result, it is suggestive of experiments to see if there is something worth following up on here.

A certain part of the concept of "health" in an organism could be seen as the correct operation of the various oscillators that are in it. This is not to downplay the importance of the various chemical and physical components which make up a living thing, but does point to the importance of the "non-material" part of a living system. Living things are sufficiently complex to support a wide variety of behaviours and states even without changing their material composition. That is to say, there are conditions (*i.e.* stress-related excessive heart rates) which can be significantly affected without the use of drugs and chemicals (*i.e.* by consciously controlling breathing).

There is great danger here of adopting a pseudo-scientific approach and supporting all sorts of quackery. I want to be very clear here that I want to support a point of view which is based on reasonable science and, most of all, subject to rigorous scientific tests. That said, I would like to suggest some thoughts for research and investigation motivated by the central idea that oscillators of widely different frequencies can be strongly coupled in biological systems.

Following Swain[2] one may imagine therapeutics based on driving biological oscillators with microwaves and/or visible photons. We have already considered the possible value of modulations of breathing, but in addition it may not seem quite so far-fetched to consider sound and music. Drumming is well-known in many traditional cultures for the production of altered states of consciousness, and reflects acoustic driving of electrical activity of the brain. An altered mental state (*i.e.* relaxation) produced in this way may then change heart and breathing rates (*i.e.* slowing them).

One should note that, as is the case with any attempt to alter bodily functions, that there are possible dangers involved. It is well known in yoga that there are dangers associated with drastic and prolonged modifications of breathing patterns. There is also the phenomenon of photo-induced epilepsy, where flashing lights at frequencies near those of brain waves can induce seizures in susceptible persons, and there may be acoustic analog effects.

With that warning in place, it may well be useful to look at the healing potential of music, sound, light suggested by traditional and alternative medicine as well as to investigate new possibilities provided by modern technology including ultrasound, radio waves and microwaves, *etc.*

Environmental medicine

If one is willing to broaden one's view of a living thing to a living thing coupled to its environment, one may well ask what the consequences are of disturbing the oscillations in nature which would normally affect our own biological oscillators.

For example, until the relatively recent advent of mechanical clocks and electric lighting, we lived in fairly close synchrony with the day-night cycle of wherever we were. What are the effects of a society where one wakes up in darkness, works indoors without exposure to sunlight (including ultraviolet), and then goes to sleep again in darkness? Here we see the ultraviolet periodicity removed completely, and the day-night natural light cycle replaced by a completely artificial one.

There is a widespread tendency to regard "clock" time as somehow more fundamental than the day-night cycle with its irregular length – long days in the summer and long nights in the winter. But it is well known that the laws of physics themselves are invariant with respect to a reparametrization of time – that is, whatever you called "t" can be replaced by g(t) where g is a monotonic function (to maintain causality). Why do we value "clock time" over planetary or biological or psychological time? The answer is that physicists usually define time ("clock time") in order to make motion look simple. As Yogi Srivastava[4] once told me, "time is an isolated very heavy mass moving along" (or something like that). The idea of an isolated heavy mass is that isolation reduces the chance for any forces to affect it, and heaviness implies an inertia that makes it relatively unaffected by whatever forces there are. Time is then conventionally defined so that the mass covers the same distance in each equal unit of time (the mass will move at a constant speed) – that is, "time" is defined in order to make motion look simple…but there is nothing fundamentally deep about conventional definitions of time. (Oddly enough, and this is rather amusing to me, the deep realization that one might want to seriously consider biological or psychological time on the same footing as "clock" time comes more from general relativity than from biology!)

Certainly there have been concerns raised in recent years that there are adverse health effects for night workers and for people who are exposed to light during the night which could interfere with circadian rhythms and melatonin production. Have we made mistakes setting our lives in synchrony with time defined according to a convention for mathematical convenience in the description of simple physical systems?

What other natural frequencies have we interfered with? We have replaced the natural radio waves around us with a variety of transmissions for communications which are often generally lumped together as “electrosmog”. At low frequencies the Schumann resonances of the cavity formed by the earth and the ionosphere have been supplanted by large amounts of 50 and 60 Hz radiation from power lines. Additional contributions also come from the associated flicker rates of television screens.

The advent of fluorescent lighting has resulted in an additional driving at 100 or 120 Hz (the “flicker” due to the alternating current at 50 or 60 Hz), and with a light spectrum significantly distorted from natural sunlight. Newer LED-based lighting could result in even more radically altered spectra which just give the visible impression of “white light”, while actually being the sum of a few almost pure colours.

These ideas are potentially quite disturbing. The usual arguments raised against potential dangers of electrosmog are that the currents induced in the brain by most artificial radio and microwave sources are quite small and certainly cause thermal effects which are negligible compared to expected temperature fluctuations. But if there are effects which can be produced by the miniscule signals produced by the retina in response to a flickering light (which is certainly the case for photo-induced epilepsy), all this may need to be revisited.

Air conditioning, motors, etc. provide still other non-natural driving frequencies, as do driven oscillations of buildings (which are sometimes associated with so-called “sick building” syndrome).

What stresses (or even diseases) do we bring on ourselves by changing the spectrum of excitations we drive our bodies with in ways that are different from those in nature? How may we impact other living systems that comprise our environment through our own changes in the ambient excitation spectrum (electromagnetic and acoustic)? How may we harm elements of our environment, and more importantly, how may we heal it and work and live within the ecosystem in a more harmonious fashion?

These are all important issues, and in many ways ones which have been raised by many people from indigenous peoples to environmental groups. Perhaps there is also a way to see some value in these ideas starting from science, and even more importantly, reach some concrete understanding of where risks may lie and what we could do about them.

Acknowledgement

I would like to thank all my colleagues at the IIB for continued support and encouragement, and especially Fritz-Albert Popp, a true visionary who more than anyone made me aware of the importance of coherence, Fröhlich’s work and biophotons, as well as the importance of a broader biophysical approach to biology and medicine. Happy Birthday Fritz! I would also like to thank the US National Science Foundation for funds in non-biological physics. Thanks also to Kaća Bradonjić for proof-reading the manuscript and for valuable comments and Rajendra Bajpai for his editorial and organizational skills. Finally I would like to thank Allan Widom and Yogi Srivastava for useful conversations about large upconversions.

References

1 Widom A, Srivastava Y N & Larsen L, Energetic electrons and nuclear transmutations in exploding wires, http://lanl.arxiv.org/abs/0709.1222.

2 Swain John, On the possibility of large upconversions and mode coupling between fröhlich states and visible photons in biological systems, http://lanl.arxiv.org/abs/physics/0603137, included in Popp Fritz-Albert, Beloussov Lev, Klimek Wolfgang, Swain John & Yan Yu, in Proceedings of the centenary symposium for Herbert Frohlich, August 2005.

3 Fritz-Albert Popp, private communication.

4 Srivastava Yogendra, private communication.