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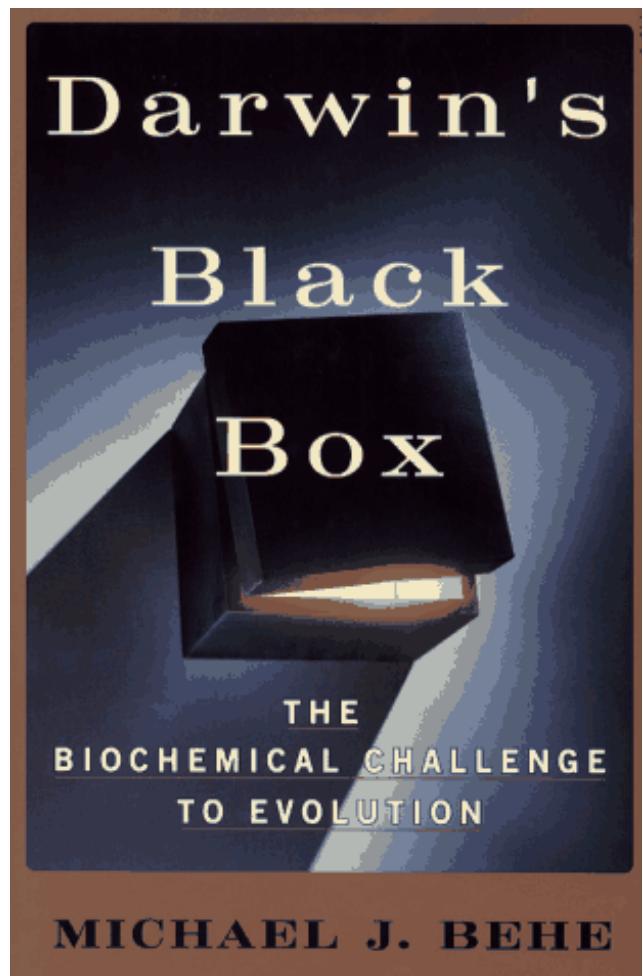
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# A Biochemist's Response to "The Biochemical Challenge to Evolution"

A Review of "DARWIN'S BLACK BOX- the Biochemical Challenge to Evolution", (The Free Press, New York, 1996). for Bios magazine; most of the text for this review was written in July, 1998.

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## OUTLINE

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I was delighted to hear of a book written by a Biochemist, questioning whether "gradualism" could explain the origins of complexity. The problem seems pretty clear - how could you possibly explain the origin of complex, interdependent biochemical systems, with a step-by-step reductionistic approach. I have been interested in evolution and the origins of complexity, and so was looking forward to reading Michael Behe's "**DARWIN'S BLACK BOX - The Biochemical Challenge to Evolution**".

However, as I began to read the book, I became concerned (and frustrated) by some of the statements made (rather dogmatically) about "modern biochemistry". I feel that although Behe asks a good question - and the subject of the book has potential for some really interesting problems to be dealt with - his manner of presenting the arguments made the topic appear more translucent (or occasionally opaque) rather than clear. Many of my biologist friends tell me that few "modern biologists" believe that Darwinian gradualism on its own can fully explain evolution - that most of them agree that there are aspects of punctuated evolution mixed with the more slow gradualistic evolution. I had expected the book to deal more with this, or perhaps to discuss some of the new ideas concerning origins of complexity in terms of "self organization" systems, instead of a general debunking of natural selection altogether. This review is my own personal response to Behe's "**biochemical challenge to evolution**".

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### What I LIKED about the book:

- Behe does a good job describing Biochemical systems and making them interesting to the reader.
- He is trying to deal with a very real and important question: the origins of biochemical complexity.
- He takes somewhat of an "anti-reductionist" stance. That is, you can't fully explain EVERYTHING in terms of simpler parts.
- He seems to be saying that science might not be able to explain everything.

## What I DISLIKED about the book:

- Although Behe says that he believes in "Evolution by common descent" in the introduction, he seems to contradict this later in the book. I am really quite skeptical of the idea of God (or the "Intelligent Designer") creating some amoeba 3.5 billion years ago, with all these IC systems. Why is this any better (or different) than Francis Crick's Panspermia theory, where space aliens seeded the earth with bacteria a couple of billion years ago?
- There are many places where, when the arguments presented can be put to the test, they fail miserably. For example, his insistence of the absence of literature about molecular evolution. This is easy to test, and see that what he is claiming is clearly wrong. This greatly reduces his integrity, in my opinion.
- When reading the book, I get the feeling that Behe is implying some sort of "conspiracy" amongst scientists. I am convinced that what motivates many very good and talented scientists is the desire to be RIGHT and to be the first one who got there.
- The appeal to ignorance of the reader. Many things are said to support his arguments which are simply not true, but the intended reader would likely have no idea of this.

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**"Yet for the Darwinian theory of evolution to be true, it [modern biochemistry] has to account for the molecular structure of life. It is the purpose of this book to show that it does not."** (page 25)

Molecular biology [or "modern biochemistry"] DOES indeed provide a very convincing basis for describing the evolution of life, at the molecular level, contrary to the central thesis of Michael Behe's book. It is the purpose of this review to have a careful look at Behe's arguments, and to point the reader towards evidence that biochemistry CAN in fact account for the origins of the complex molecular structures of life.

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The basic premise of the book is that **"Biochemistry has pushed Darwin's theory to the limit. It has done so by opening the ultimate black box, the cell, thereby making possible our understanding of how life works."** Basically, life is so complicated, Behe claims, that it MUST have been created by divine intelligence, or at any rate gradual evolution could not possibly have created such complex systems, and most scientists ("biochemists") know this but are just too proud or embarrassed to admit the obvious fact of intelligent design:

**"The result of these cumulative efforts to investigate the cell - to investigate life at the molecular level - is a loud, clear, piercing cry of "design!" The result is so unambiguous and so significant that it must be ranked as one of the greatest achievements of the history of science..."**

**But no bottles have been uncorked, no hands slapped. Instead, a curious, embarrassed silence surrounds the stark complexity of the cell. When the subject comes up in public, feet**

**start to shuffle, and breathing gets a bit labored. In private people are a bit more relaxed, many explicitly admit the obvious but then stare at the ground, shake their heads, and let it go at that.**

**Why does the scientific community not greedily embrace its startling discovery? Why is the observation of design handled with intellectual gloves? The dilemma is that while one side of the elephant is labeled intelligent design, the other side might be labeled God.**" (pages 232-233).

So basically Behe is invoking a conspiracy theory from within the scientific community, on the order of "X-files". Here's a job for agent Mulder to investigate! The scientific community knows "the truth", but doesn't want to admit it, for fear of theistic implications. There have already been [numerous reviews of this book](#), and in a sense I feel a bit hesitant to add yet another one here, but I also feel it is important to communicate my opinion of this book to the readers of Bios magazine (undergraduate biology majors), especially after the release of the paperback version a few months ago and the continual presence throughout the spring of 1998 of the hardback version as number 1 best-seller on the Amazon.com list of evolutionary titles (the paperback version, which came out in March of 1998, has been climbing quite quickly within the top 20 as well). Obviously this is a popular book. Behe's challenge should be taken seriously, and the positive aspects as well as the negative should be exposed.

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## 1. A look at Behe's arguments for "irreducible complexity"

One recurrent theme in the book is the concept of "irreducible complexity", for which the household mousetrap is used as an example. The argument goes something like this: You need at least 5 essential components for the mousetrap to work - a platform, holding bar, spring, catch, and hammer. If any of these are missing, the mousetrap fails to work. Perhaps this analogy works for things built by humans, but I think it is very dangerous and misleading to try and extend it to molecules - in this case, biochemical systems and evolution. Why? Although chemists can at times think of molecules as little tiny spheres, which may or may not interact, it is difficult to visualize individual mouse-trap components interacting with each other in the same way. Chemists have managed to do a pretty good job of explaining many aspects of the world in which we live, while still holding on to the idea that an ATOM is the smallest indivisible unit, representing the different elements. (This is an idea going back to the Greeks - Democritus, in the 5th century B.C.. Yes, of course we know that atoms are in fact made up of smaller particles, but you can explain much of chemistry with just simple atoms, made of protons, neutrons, and electrons.) The point is that for a chemist, molecules interact with each other at the level of individual atoms - which themselves are a complex assembly of parts - not "mouse-trap" parts. Behe argues that certain biochemical systems have a minimal level of complexity, and they must exist, either fully assembled and functional, or in some incomplete and non-functional form (and hence useless, from an evolutionary perspective). I will go through each of his 5 examples of "irreducible complexity".



The **first example** of irreducible complexity is of the flagella and cilia. I will focus on flagella, because they are more simple, and I'm more familiar with bacterial systems. Behe concludes that both of these systems are examples of irreducible complex: The cilia are composed of more than 200 different proteins, and "**the bacterial flagellum, in addition to the proteins already discussed requires about forty other proteins for function**" (page 72) and all of these (more than 240 proteins) are necessary to function, just like a mousetrap. This is something that is concrete and the numbers are easy enough to compare with what is known. If all the components are essential for function, you wouldn't necessarily expect there to be lots of variation - if you found some fully functional mousetraps with 3 components (of the 5 that are "required") and these mousetraps were still functional, you'd have to reduce the number of required components from 5 to 3.

If you look at bacterial flagella, you find that some are indeed quite complicated, but others are more simple. For example, the basal body can vary with species - in *E. coli* there are four rings, in *Bacillus subtilis* two rings, and in *Caulobacter crescentus* five rings. I can easily imagine a scenario where a "primitive bacterium" might have one ring, and then you have a flagellum with two rings, then three, and so on. This is a "gradual, step-by-step" evolution, which is the antithesis of Behe's argument. Furthermore, this could easily happen through such well documented events as gene duplication, or a simple mutation in the DNA sequence which would then code for a different amino acid, perhaps allowing two copies of the same protein to dimerize together.



The complete genome of the bacterium *Mycoplasma genitalium* has been reported in 1995, a year before "Darwin's Black Box" was published. This bacterium has (at the very most) about 470 different proteins. Many other bacteria (with flagella) have genomes that are quite small. Based on the complete sequences of different species of bacteria, a minimal set of about 256 genes necessary for survival has been estimated. If what Behe says is true, a very large fraction of the total proteins must code just for the flagellum in bacteria! (e.g., the simplest possible bacteria with a flagellum would need about 500 proteins, more than half of which would be necessary for the flagellar apparatus) For *Escherichia coli*, there are about 40 proteins needed to make the bacterial flagellum - so perhaps I did not understand what Behe was saying - maybe he was saying that a flagellum has a "minimal complexity" of these 40 proteins. (note: YES, it looks like I was wrong here - see update below for more on this!) However, in the bacterium that causes syphilis (*Treponema pallidum*), there are a total of 38 flagellar proteins; in the bacterium that causes lyme disease (*Borrelia burgdorferi*), there are only 35 flagellar proteins; finally, in a bacteria associated with ulcers (*Helicobacter pylori*) there are only 33 proteins necessary to form complete, fully functional flagella. It is likely that as new bacterial genomes continue to be sequenced (at the rate of about one a month!), organisms will be found which require even fewer genes to make a completely functional flagella.

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So Behe has overstated the case a bit. Instead of an "irreducibly complex" system consisting of more than 240 (or even a "mere" 40) absolutely essential proteins, there exists documented examples of organisms with only 33

proteins necessary for fully functional flagella. But the jury is still out - perhaps a bacteria will be found with even fewer proteins. I say let's wait until the dust settles a bit and see where we stand. Yes, I would readily admit that there is STILL the problem of the evolution of the "minimal flagellum" - but in fact many of these proteins are similar enough to each other (and/or genes for other functions) that a simple series of gene duplication events could explain their origins. This type of mechanism is not something hypothetical - it is based on known, observed cases where natural genetic recombination results in two copies of a gene (or sets of genes); this mechanism occurs quite readily, and it is something that is often demonstrated in an undergraduate molecular genetics lab. As far as whether a partially functioning flagellum provides any benefit at all - experiments in which some of the proteins have been mutated show that the flagellum can still aid in swimming - but not as well. I would rather be able to partially swim away from my predator than to not swim at all. In fact, I'd stand a much better chance of not getting eaten by a shark if I was in a boat and had even a crude piece of wood to use as an oar, and my friend had nothing to paddle with at all! If I manage to survive, and am not eaten, then I can pass on my crude oar to my children, and so have established "selection". My point is that a partially functioning flagella **IS INDEED** more useful than nothing at all. Once you allow for this, the idea of "irreducible complexity" loses its punch.

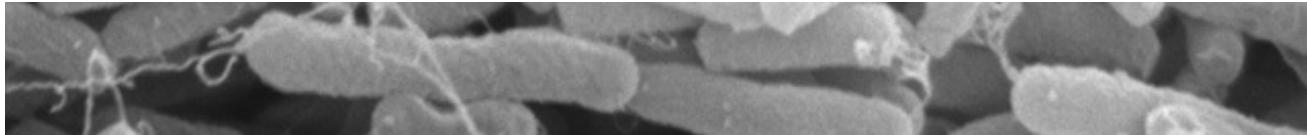
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I also found it a bit curious that Behe seems surprised by the use of a proton gradient ("**flow of acid through the bacterial membrane**") as a source of energy for the flagellum, rather than ATP. From an evolutionary perspective, this gradient is much more easy to establish and utilize, and in fact such gradients are likely to be far more ancient sources of energy. Proton gradients are used in the mitochondria of human cells, for example, to provide the energy necessary to generate ATP, which is then used as an energy currency. The ATP can then be used for many things, including conversion from chemical energy (ATP) to mechanical energy in the muscles. But in the case of the flagella, bacteria harness the energy directly. In light of this, I wouldn't call the use of an ancient and more simple proton gradient an "**unexpected discovery**". In spite of the clear possibility of gradual evolution of bacterial flagella, Behe claims (page 72) that "**Gradual evolution of the flagellum, like the cilium, therefore faces mammoth hurdles... Yet here again, the evolutionary literature is totally missing.**"

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This brings me to another simple statement that is easy to check - that "**only two articles even attempt to suggest a model for the evolution of the cilium that takes into account real mechanical considerations**" (page 68). A quick PubMed search (<http://www.ncbi.nlm.nih.gov/PubMed/>, (all the PubMed searches were done in July, 1998 - here I just typed in "cilia" and "evolution"), revealed 107 articles, many of which discuss exactly the types of mechanisms Behe claims are missing from the literature. The interested reader with web access is certainly encouraged to try this little experiment for themselves - how many articles can you find about the evolution of flagella? According to Darwin's Black Box, "**Even though we are told that all biology must be seen through the lens of evolution, no scientist has ever published a model to account for the gradual evolution of this extraordinary molecular machine.**" (page 72, emphasis his) I found 125 articles, several of which DO discuss and give models for gradual evolution of flagella, with titles such as "The **flagella** apparatus of spermatozoa in fish. Ultrastructure and **evolution**". So my point in all of this is that Behe hasn't done his homework. His main points of the chapter are: **1.)** the complexity of the flagella, as evidenced by **2.)** the large number of proteins involved in the cilia and flagella, (240 of which are required for a functional flagella), and **3.)** the absence of scientific literature on the subject. I am certainly willing to concede the

first point (that cilia and flagella are complicated), but not the latter two points (*e.g.*, this represents "irreducible complexity"). In particular, in the last point it is in fact more his IMPRESSION of the lack of papers in the scientific literature. It is important to keep this in mind when reading the final section of the book.

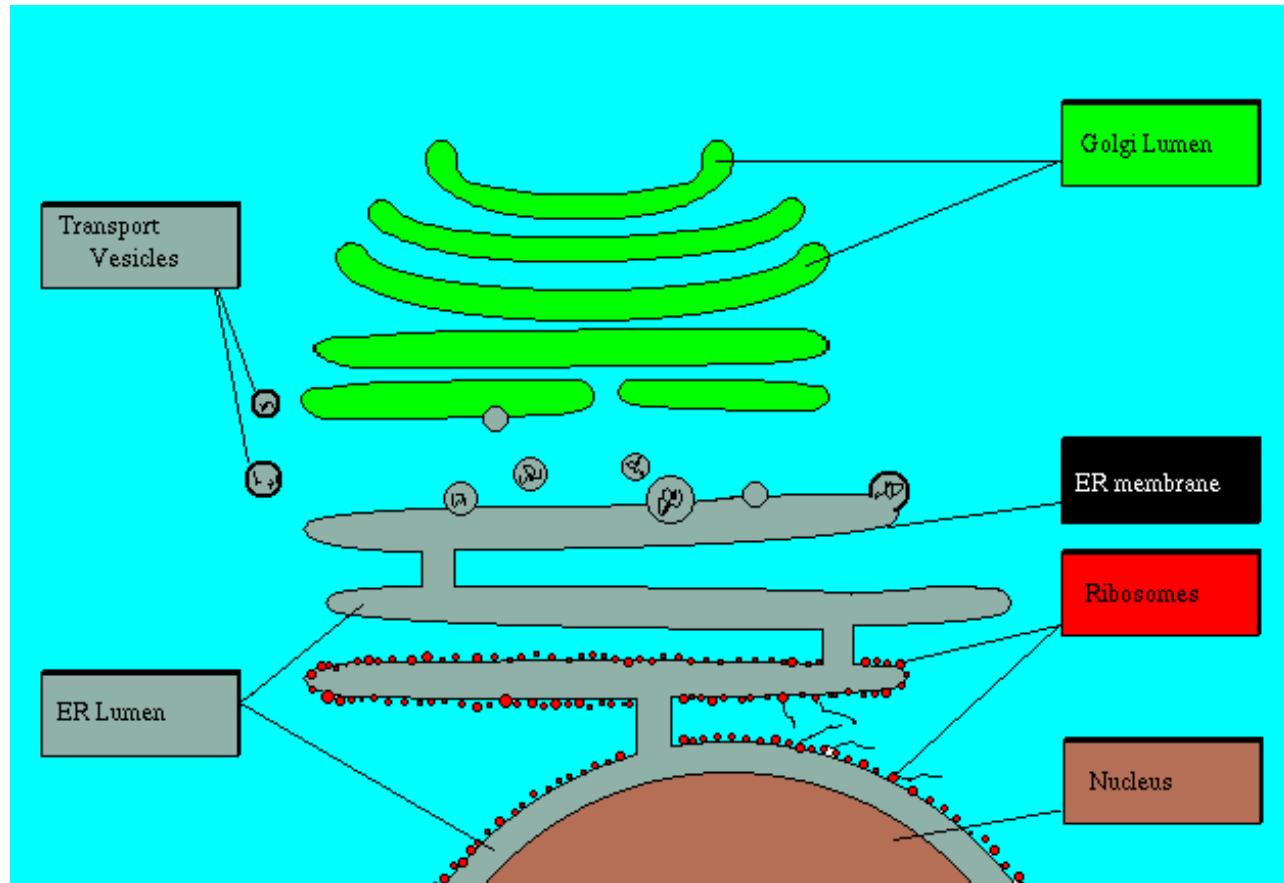


The **second example** of irreducible complexity has to do with blood clotting. As before, Behe reaches a similar conclusion concerning the published literature on evolution of the blood clotting cascade: "...**The fact is, no one on the earth has the vaguest idea how the coagulation cascade came to be.**" (page 97). A quick PubMed search (once again I encourage the skeptical reader to look for herself) revealed 27 articles that concern the evolution of the whole system. However, in addition, I just looked for articles about the evolution of "thrombin", in the past two years - and found [several interesting references](#) - especially in light of how this would fit in with the evolution of the more complicated signal cascade that Behe refers to in this section. Work is being done and published in this area - no, we don't have all the answers - but I think it's a bit presumptuous to claim that "no one" knows how this could possibly have evolved. But surely this complicated system of the formation of blood clots MUST represent an example of irreducible complexity? I am reminded of a recent visit to the "[Viking ship museum here in Denmark](#)". In the 11th century, the Danish Vikings sunk about 5 ships at the narrowest part of a fjord, in order to protect the town of Roskilde, which is further inland. The ships formed a type of man-made "reef", and consisted of assorted old ships that were readily available at the time. It didn't really matter WHICH ships they used. In fact, the ships represent different styles and types built by the Vikings over several hundred years. I have a feeling that something similar is going on with the blood clotting proteins. Basically nature uses whatever is available that will form long polymeric bridges across an open wound. Yes, the regulation of this is complex, and has been highly optimized.

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Evidence against Behe's view of irreducible complexity (and in favor of my utilitarian view) comes from an analysis of the regulatory proteins in different blood clotting systems. If the entire system is "irreducibly complex", then one should see very nearly the same regulatory system in all animals. Perhaps it is not surprising that you don't see this for the blood clotting cascade. In fact, very often you will find quite a bit of variation in "irreducibly complex" systems when you look at different organisms. But, Behe could well say, variation is one thing - origins of complexity is another. How could this complex system have evolved? Often nature will simply take what's handy and use it. Take for example the substance that forms the crystal for the lens of the eye - this is nothing but a common enzyme that happens to have very nice crystallization properties - not necessarily a "tailor

made" protein specifically (and ONLY) for this particular use (for a recent review of the lens crystallins, see [J. Piatigorsky, Ann N Y Acad Sci, 842:7-15](#)). In another example, a friend of mine had isolated the protein component of a complex which degrades RNA. She was surprised to find that one of the constituents was enolase - an enzyme used in metabolism, and having no previously known role in anything to do with RNA. ([Py et al., Nature, 381:169-172, 1996](#)) There are MANY examples of complicated systems which are constructed from components that themselves have perfectly viable roles as units in a completely different context. But please don't take my word for it - have a look for yourself in the literature and see what you can find. I invite the reader interested in further exploring this to visit [Russel Doolittle's review of "DARWIN'S BLACK BOX"](#); he spends a good deal of time discussing Behe's arguments about evolution blood clotting regulation. Doolittle claims that, according to Behe, he has wasted "the last 35 years working on proteins and evolution".



The **third example** of irreducible complexity has to do with how proteins are transported within a cell. Believe it or not, I think Behe even UNDERSTATES the level of complexity here! For example, when he describes the synthesis of a protein that is to be targeted to the lysosome (page 107), Behe mentions that going all the way from the cytoplasm to the lysosome requires BOTH gated transport, and vesicular transport. This is indeed quite complicated - he doesn't even talk about the fact that most mRNAs are originally made much longer than needed - sometimes more than 100 times longer. Then, after the "pre-mRNA" is read, intervening sequences (sometimes more than a hundred) are spliced out, (different sections are snipped out in cells in different tissues) by a special

RNA/protein (snRNP) complex called a "spliceosome". Sometimes, the message is further EDITED by changing the sequence at certain positions (!). This PROCESSED mRNA is what is then EXPORTED outside of the nucleus, using a little mechanical motor that moves along a microtubule, to the cytosolic face of the Endoplasmic Reticulum (ER - not the free cytoplasm), where it is translated. It doesn't float out. The cells are very crowded inside. The newly formed peptide chain is then threaded into the ER lumen, where it undergoes the first round of post-translational modification. Then vesicles containing the protein bud from the ER to the cis Golgi, and then subsequently go through the Golgi stack, where further protein modifications (such as glycosylation) occur. And then eventually it winds up in the lysosome. Yes, so far I agree with Behe - this is indeed a VERY complicated system. Is this system then an example of "irreducible complexity"? Are all the parts necessary? In a review of protein transport, the authors state that some proteins can direct their own secretion - that is, no transport proteins are necessary. Although these proteins do not use gated transport, they provide an example of a simple system that could well be the precursor to vesicular transport.



However, many of the proteins involved in transport have molecular "ancestors" in the form of ABC transporters in bacteria. Here you have a bacterial protein which has three different parts, or domains, which can be modified to fill the needed role in a more complicated system. The original proteins exist in bacteria, which are much smaller and have less complex intracellular structures than eukaryotes. Why doesn't Behe talk about this large family of bacterial transporters that are also found in eukaryotes? Here is a perfect example of the very type of molecular evolution he is talking about, and yet he never mentions it. If you are looking for the "simplest mousetrap", it would make sense to look at these systems in bacteria.

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Finally, the chapter ends with (yet) more claims that his literature search for articles about vesicular transport and evolution came up blank: "**A search to see what titles have both evolution and vesicle in them comes up completely empty.**" (page 114). Using the PubMed site, once again, I have found articles that Behe claims aren't there. I found 4 articles published before 1996 (example: Cowan D, Linial M, Scheller RH, "Torpedo synaptophysin: **evolution** of a synaptic **vesicle** protein.", *Brain Res.* 1990 Feb 12; **509**(1): 1-7); if I look in the abstracts as well, I pick up another 126 articles. But, please, don't just take my word for it - have a look for yourself!

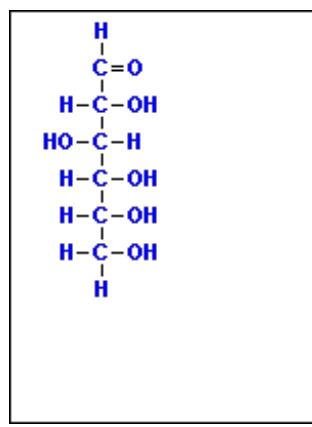


The **fourth example** of "irreducible complexity" is the evolution of the immune system. I used Behe's description of "killer T cells" as a discussion question for my introductory biology class. They learned about introductory cell biology from a chemical perspective - the importance of membranes in isolating the inside from the outside of the cell, and how protein channels and pumps maintain gradients across this barrier to provide the energy for the cell - in many ways this chemical gradient is the molecular basis for life. They also learned that most cells (including invading bacterial cells) maintain a balance where water can freely flow in and out of the cell, by keeping the ionic strength inside the cell roughly equal to that outside of the cell. The whole point is that it is DIFFERENT ions inside vs. outside. I read them the following quote from "Darwin's Black Box", regarding

how antibody proteins destroy ta cell, and asked them to explain whether they agreed with this or not, based on our discussions in class.

"...**Rather, they** [i.e., the proteins] organize themselves into a tubular form that punches a hole in the membrane of the invading bacterial cell. Because the insides of cells are very concentrated solutions, osmotic pressure causes water to rush in. The in-rushing water swells the bacterial cell till it bursts." (page 134).

The main problem with his explanation is that the bacterial cells don't "burst" due to the water rushing in; the water is already pretty much equilibrated across the membrane. The cells die because their chemical gradients have been destroyed. I am quite surprised that someone who's writing a book on "the molecular basis of life" apparently doesn't understand the basic chemical principles of life! Meanwhile, getting back to the subject of the immune system, apparently, Behe has never heard or thought much about the immune system in invertebrates. This is once again an example of not doing his homework - he is trying to explain vast fields of subjects which are difficult for people who have been studying for many years to master. Since Immunology is NOT my area of expertise, I consulted the professor in the department who teaches immunology, borrowed a current text, and found an entire chapter devoted to the evolution of the immune system (yes, it includes a discussion at the molecular level), with many references to the primary literature. I would encourage the interested reader to use a similar approach. Since then, I have read an excellent book (for the "non specialist") about the immune system, which I can wholeheartedly recommend - William R. Clark "AT WAR WITHIN: The Double-Edged Sword of Immunity", Oxford University Press, 1995; he does indeed discuss evolution of the immune system in the Appendix, but I would recommend reading the whole text first!. As has become customary, Behe ends the chapter with a lament about the lack of literature published on the evolution of the immune system. (A PubMed search yielded 84 articles on "molecular evolution of the immune system".)



The **last example** of "irreducible complexity" is a description of metabolic pathways. Like several of my biochemist friends, I have three large posters on my wall, with all the different metabolic pathways outlined. It has become so complicated that the biochemical company that makes the charts also provides a book where you can look up a particular pathway, like finding a city on a road map. (I have a "you are here" sticker, near the synthesis of DNA.) The metabolic pathways are certainly a nightmare of organization. This obviously is complex - there are THOUSANDS of biochemical pathways. The reader will be surprised to hear that at this point I do think that perhaps in a limited sense Behe's sense of "irreducible complexity" might apply to this system. (FINALLY! This was Behe's last example!) I had mentioned earlier that there was a "minimum level of complexity" of around 256 or so proteins, in order for a free living bacterial cell to survive. Of course, this is a lower limit, and most bacteria contain more proteins than this. For example, the common bacteria *Escherichia coli* contains about 4600 genes. The interested reader is encouraged to visit the ["EcoCyc" page on the web](#), where all of the metabolic pathways for *E.coli* can be seen in all its complexity. How could such a complicated system have possibly evolved? Benno Müller-Hill has estimated that there are 300 or so distinct families of protein structures in *E.coli*. (B. Müller-Hill, ["The lac Operon: A Short History of a Genetic Paradigm"](#) Walter de Gruyter, Berlin, 1996). So in this sense, perhaps there is a threshold of complexity, of around 250 to 300 proteins necessary for a free living cell. Does this mean that a primitive cell with 250 or so proteins is "irreducibly complex"? Perhaps. However, in terms of evolution, the synthesis of proteins (and much of metabolism, for that matter) probably came LONG AFTER the first type of cells. I think basically what you need is a system capable of self reproduction, that's not TOO perfect, and then

some sort of selection. If you add to this a membrane coat, and some sort of very simple chemical gradient, you're on the way to formation of a very simple, primitive "living organism". I'll come back to this in the next section.

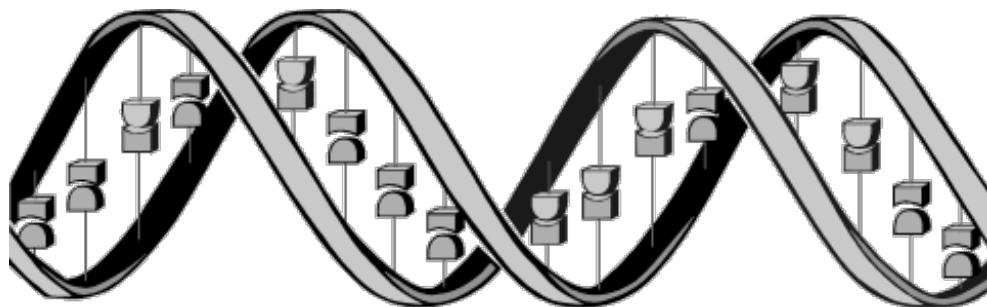
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So much for the specific examples. One could argue that it is always easy to find some fault in any argument - how would I rate the overall philosophical tone of the book? Do I agree with Behe's conclusions? I'm certainly not opposed to the concept of "intelligent design", but, as the once popular T.V. ad put it - "where's the beef?" I don't think Behe has done an adequate job of building his case. This makes it difficult to discuss his philosophical conclusions, since his main argument seems to be the existence of biological complexity and the absence of molecular explanations for its gradual evolution. [A recent review of "Darwin's Black Box" has as its title "The latest attack on evolution is cleverly argued, biologically informed, and wrong"](#). Perhaps Behe is informed for a **protein biochemist**, but I'm not so sure that Behe really is **biologically informed!** The truth is out there, despite the claims to the contrary in "Darwin's Black Box". I want to turn my attention now to a more positive statement of the evidence I find in favor of molecular evolution.

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## 2. Evidence for the biochemical origins of molecular structures of life.

There are several things that the author conveniently forgot to mention in his explanation of "biochemistry". I shall focus here on only two related items: the structures of nucleic acids, and the genetic diversity of life. Both of these are areas where some of the "missing evidence" for the molecular evolution of life can be found.



### THE STRUCTURES of Nucleic Acids

In the appendix, Behe provides a description of "The Chemistry of Life". I think he does a pretty good job of describing membranes and protein structure. However, when he comes to nucleic acid structure, he refers to the deoxyribose SUGAR of DNA as a "carbohydrate" - this is a bit picky I know, but in my 20 years of working with

DNA, I cannot remember anyone who refers to the simple deoxyribose sugar as a "carbohydrate". (According to my dictionary of Biochemistry, this can be used "although it is inaccurate from a chemical point of view", since the sugar in DNA is not of the formula  $C_n(H_2O)_n$ ). This is certainly only a minor point. However, I kept waiting to see what Behe had to say about the self organization of nucleic acid bases. If you were to take some Adenine, for example, and throw it into solution, it would self associate, and form a HELIX. This is the SAME type of self assembly that Behe readily discusses for liposomes and even for ribosomes (although he seems a bit surprised:

**"Incredibly, the ribosomes self assembling"**). There is nothing "magic" about how the bases stack on top of each other, it is just pure and simple chemistry - due to the hydrophobicity of the bases. The bases are merely seeking a thermodynamic minimum. Perhaps this has somehow not made it to the introductory level biochemistry textbooks, but it is certainly well known, and of course has direct bearing on the possible evolutionary origins of RNA and DNA. (For a reference see [Calladine & Drew's wonderful book "UNDERSTANDING DNA - The Molecule and How it Works"](#) and/or [visit my "DNA is like Coca-Cola" web page](#)). If free bases stack on their own and form a helix, it is not too difficult to envision simple molecular linkers connecting them together. The free bases, and necessary "linkers" to form a primitive type of polymeric nucleic acid, can be formed from simple inorganic material plus a bit of sunlight.



I thought about Michael Behe's book recently while I was listening to a lecture by Tom Cech (FEBS '98 Silver Jubilee conference, July, 1998). Behe leaves the reader with a very different perspective of biochemistry than one would get from attending this week-long meeting of the Federation of European Biochemical Societies. This conference is all about biochemistry - in fact, there were more than 40 different disciplines represented, ranging from metabolism to cell adhesion to molecular phylogeny - the latter is a subject which Behe feels is somehow perhaps a fringe element of biochemistry. I remember reading in his book that the word "evolution" seldom appears in the index of a biochemistry textbook, but it certainly was a major theme throughout this conference - discussed in all the major lectures.

I realized that Behe had been a bit unfair in his description of "The RNA World" (page 171). In a footnote, Behe says **"Cech won the Nobel prize for his work. The awarding citation alludes to the impact of Cech's work on origin-of-life studies. Cech himself, however, rarely mentions the origin of life in connection with his work."** (page 283) The talk I heard on Tuesday morning, given in a large auditorium, with perhaps a thousand people attending, was all about Cech's work on the molecular origins of life. The experiments on molecular evolution of RNA started in the early 1980's and are continuing today. I found 17 of his papers where he discusses molecular evolution, the most recent was a few weeks ago, and the others are spread out, dating back to 1982. Again, I used the PubMed link - just type in "Cech TR and Evolution". He has done what good scientists do - designed a hypothesis in terms of simple questions that can be addressed experimentally, and then tested this with experiments. Sometimes you are "right" (e.g., the experiment works and validates the predictive power of your theory), and sometimes you're wrong - but scientists are willing to TEST their ideas. Of course what also must happen is that OTHER people must be able to reproduce ("test") your results. The hypothesis was the following: ribosomes are made of a mixture of RNA and protein. Is it possible that at one time ribosomes consisted ONLY of RNA, and no proteins? If this were true, you should be able to find an RNA molecule (or set of molecules) which could combine with the present rRNA and be capable of synthesizing proteins - with no ribosomal proteins required. They designed an "*in vitro* evolution" set of experiments, and found the necessary RNA, and got it to work. This is a pretty major advance in terms of understanding possible molecular mechanisms for the origins of a complex system - the synthesis of proteins.

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Tom Cech also presented the crystal structure for a self splicing RNA. The amazing thing is that, when he compared this to an enzyme, they looked similar. Basically, in order to catalyze a chemical reaction, you just need to be able to have the right chemical groups in the right place, and the rest is just "scaffolding" - it often doesn't matter WHAT the size or shape of the material is, so long as the reactive groups are properly localized.

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And here is where I think Behe really misses the point. Throughout the book he almost leaves me with the impression he's looking for an explanation for the evolution of complex PROTEIN systems. Well, complex protein systems don't evolve, and proteins don't evolve, but DNA sequences do. In fact, when examined at the molecular level, evolution can be seen to occur in "jumps" sometimes! These sudden, major changes occur through the introduction of new genetic material (*i.e.*, DNA sequences) which had been previously either non-existent, or present but not able to express itself. Where do the extra DNA sequences come from? Often through copies of itself, or gene duplication, or from other organisms, via any one of a variety of mechanisms, such as transposable elements, viruses, and homologous recombination. This is not some postulated, theoretical mechanism - this is something that can be seen to happen VERY OFTEN in every organism we have ever looked at - this is why individuals are unique - why you are different from me. So really, if you want to know about molecular evolution (**the theme of this book!**), it makes perfect sense to talk about changes in the DNA sequence, which can result, of course, in changes in the protein sequence and can also affect whether the protein gets made at all, and how much of it gets made.

## The Variation of Nucleic Acid Sequence in life.



In order for evolution to occur, you need the following three things: a system of inheritance, variation within that system, and some sort of selection. In the above case, Cech made the variation artificially, such that you had perhaps more than a million different sequences from which to choose from. What is the variation like in "the real world"? To exaggerate Behe, if you dare to change a single amino acid in a protein, you could destroy its function. However, using the same "classic" example of the hemoglobin gene and sickle cell anemia, it is easy to ask the question: how much variability can you have within the protein? Behe readily admits that you see a bit of a change between the hemoglobin of horse and humans. In fact, you can have different amino acids for MOST of the positions of the hemoglobin proteins, but ONLY A CERTAIN FEW positions are so important that they cannot be changed. Thus, it is NOT a case of certain death if you change ANY of the amino acids. Furthermore, the "step-by-step" gradual changes you see in the amino acid sequence of the hemoglobin protein can be explained quite simply and logically by gradual evolution. I think Behe concedes this point - he's interested in the evolution of complex systems. But my point is that even within complex systems, you have a tremendous amount of variation within a population of organisms, and hence the potential for change by natural selection.



How much variation is there in the DNA sequence? I was quite surprised to learn of the enormous variance

between humans. One out of every thousand males has an extra X chromosome, and a similar number (one out of a thousand) of males have an extra Y chromosome. About one out of every thousand females only have one X-chromosome, instead of two. If you were to have a look at the DNA sequence for any two human beings, there would be more than a MILLION base pair (bp) difference between them! Many humans carry major chromosome translocations, where part of the arm of one chromosome has broken off and been attached to another chromosome. Think about this - there are roughly 3,000,000,000 bp in the human genome. Even if you were to copy this at an error rate of only one in a million, which is pretty close to what happens in the real world, then you will still get 1000 bp difference EVERY time the cell divides. All humans started out as a single cell, which divides many times over - hence the DNA sequence is quite diverse, even within different cells from the same person! How can we possibly survive all this variation? Most (about 98%) of the DNA in humans does not code for proteins, so we can take quite a bit of deterioration in sequence and still live. Furthermore, the mutations (changes in DNA sequence) are not in fact completely random, but somewhat localized to regions that are not as essential for life.

There are many well documented cases of new species arising from large scale changes in the DNA sequences. For example, in simple cases, the chromosomes get duplicated. This is the likely origin of trout fish - if you examine the trout cells, they contain FOUR copies of each chromosome of a smaller related fish, rather than the expected "normal" two copies. This extra set of genetic material not only make the trout larger than their ancestors, but gives them extra space to change and adapt with. This happens very often with plants, although complete polyploidy is much less common in animals. This is how many plants have obtained such large genomes - some more than a thousand times the size of the human genome!

The smaller changes, such as gene duplications, are also well documented. Transposable genetic elements can splice themselves in and out of genomes, creating duplicate copies of genes, and also causing problems for the genomic organization and stability of organisms. At the level of bacteria, it is possible to look at complete genomes, and [see which regions have come from bacterial viruses](#). A bacterial virus is really quite simple: a small piece of DNA and a protein coat. That's all. Pretty simple. Yet this is a very powerful mechanism of introducing genetic change in bacteria. Similarly, eukaryotic viruses can bring foreign DNA sequences (*e.g.*, from other organisms) into human cells. So the genetic information is varied and constantly changing.

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Behe is quite skeptical that sequence analysis will yield any useful information concerning evolutionary origins:

**"One would have hoped that finding proteins with similar sequences would lead to the proposal of models for how complex biochemical systems might have developed. Conversely, the fact that such sequence comparisons do not help us understand the origins of complex systems weighs heavily against a theory of gradual evolution."** (page 285, footnote to chapter 8)

I think Behe has confused the process of GRADUAL evolution, with the problem of origins of complex systems. GRADUAL evolution certainly does occur, and has been well documented through sequence analysis, although I agree that this cannot FULLY explain the sudden emergence of complex systems. However, it is important to point out that we can understand quite a bit about evolution, in terms of changes in DNA sequences. There are certain sequences that code for RNA structures which can loop out and direct DNA synthesis of itself and insert itself into another location in the chromosome. By examining the DNA sequences of complete bacterial genomes, it is possible to see "molecular fossils", which are kind of like ancient meteor craters - the remnants of events that happened in ancient times, long ago. This is an exciting part of my research - I personally am amazed at the wonders of Creation. Furthermore, I don't think that understanding HOW this works prevents me from believing in God and a purpose of life. I think that looking at nucleic acid sequence evolution is a good place to start if one is truly interested in understanding the molecular evolution of life. It is certainly capable of explaining much - not all - of what we see in the world around us presently.

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### 3. The larger philosophical picture

"All is dark, obscure and open to dispute when the cause of a phenomenon is not known; all is light when it is grasped."

-Louis Pasteur

The "**Biochemical Challenge to Evolution**", according to this book, is that now that "**modern biochemistry has uncovered the secrets of the cell**", there is "**an eerie and complete silence**" in the scientific literature about molecular evolution. Essentially, now that we fully understand how cells work at the molecular level, most scientists are very much aware that Darwinian evolution cannot possibly explain the complexities of life. Perhaps (grudgingly) Darwinian evolution might work at the organismal level, but it falls apart for lack of evidence at the biochemical level, according to this version.

Michael Behe's book reminds me of a cartoon, where a scientist has filled the blackboard with equations, and then he says, in exasperation, "Then a miracle occurs!". The question is - must God necessarily be restricted in the method of creation, such that the only options are ones that science has not (yet) explained? Is it possible that God could use natural processes to create life? I think that, in fact, this line of belief has been held by Jews and Christians for more than 3000 years. It is only very recently, within the last few hundred years, when scientists disproved spontaneous generation, that some theologians decided to try and hook their theology to the shifting sands of modern science - and this has been a source of problems ever since. Presently the trend of Darwin bashing is limited mainly to the U.S. - I have spoken with many people here in Europe who attend synagogue or church regularly, and all of them have no problems accepting science (including Darwinian evolution) and their view of God. Very few of them have even HEARD of the "creationism" common in many parts of the U.S.

For the few readers that have made it this far into the review, I want to try and put "The Biochemical Challenge of Evolution" into perspective. Behe is opposed to Darwinian evolution, but claims he's no creationist - he also realizes that there is evidence the world is older than 10,000 years. He even makes a



bolder statement: "**Further, I find the idea of common descent (that all organisms share a common ancestor) fairly convincing, and have no particular reason to doubt it....**" (page 5). (This is a major concession for many of my traditional creationist friends in Arkansas.) If one believes in "common descent", then this might create a bit of a puzzle in terms of the intelligent design argument. Is the "intelligent design" only visible at the molecular level, and not to be readily seen at the organismal level? If you allow for the evolution of complex systems from simpler systems in anatomy, for example, at what point could you say intervention by the Intelligent Designer must occur? Last December (1997), I watched [a debate considering whether creationism should be treated equally with evolution in the public schools](#). The side FOR creationism included Michael Behe and William F. Buckley; on the "evolutionist" side was Michael Ruse, among others. (Michael Ruse is in fact a Christian who has written an excellent book, "[But is it Science?](#)" about evolution vs. creationism.) DARWIN'S BLACK BOX had a very favorable write up in Christianity Today (presenting Behe as an anti-evolutionist), and has received much positive attention from many in the religious community, who delight in his attacks on gradual evolution. I know that Behe would not consider himself a creationist - but here he is, on the debate team arguing that Creationism should be taught in the schools. I want to stress once again that I am not opposed to anyone wanting to express their religious belief. But I do have real problems with people who want to somehow use science to make their invisible God, "visible", and then insist on [teaching this doctrine as "science" in the public schools](#). My point is that for the life of me, I cannot understand why so many people consider it a necessary part of their BELIEF in an all powerful God to put restrictions on the method of creation. They say that God could not have used evolution - and not only that, but they won't allow anyone to teach evolution as "science" because of their theological objections. But I'm straying from the topic here. Behe, to his credit, spends most of the book arguing from a factual perspective. So surely the best thing is to judge the book on the facts.



I think Behe has exaggerated the case - at the expense of the credibility of his argument, in my opinion.

- First, he **OVERSTATES** the case for our present state of knowledge. Behe claims that explaining evolution was "easy" before modern biochemistry discovered how complex life really is, and now that we have this vast amount of knowledge about how the cell works, we realize that it is simply too complex to have evolved by gradualism. However, as I've mentioned before, explaining the origins of complex systems has been a problem for evolution at the organismal level as well. The punctuated equilibrium theory, as an alternative to gradualism, was postulated based on the fossil record of the evolution of biological organisms, before much of the revolution in molecular biology occurred.

I think that Behe is overly optimistic in portraying our present level of understanding of the biochemical functions of the cell. By painting such an ideal description of how much we know, it then, logically, seems difficult to understand why (according to his arguments) no one has been able to come up with any explanations for the evolution of complex systems. I think perhaps he should tone down a bit the idea that now we fully understand the molecular workings of the cell. For example, it is easy to find such statements as this: "**Over the past four decades modern biochemistry has uncovered the secrets of the cell"** (page 232). I think perhaps he should be a bit more realistic and say something like "over the past four decades, molecular biology has *begun* to uncover *some* of the secrets of the cell." If I didn't know anything about biochemistry, it

sounds like we presently almost have fully solved how the cell works.

In another example, on page 175, he says "**In the late 1970s, quick and easy methods became available for sequencing DNA...**" This needs to be put into a broader perspective. Imagine that you are in the Library of Congress, and you've just learned how to distinguish the letters of the English alphabet, at a rate of a few minutes for each letter. Do you think you're ready to tackle the total meaning of all the books in the library and their origins? I suppose one could argue about what "quick" means, but if one were to decipher the DNA sequence of a single human cell, at the rate of the total world output in 1979, it would take more than 4,000,000 years! In fact, about 6 or 7 years later the U.S. government launched a 20 year project to sequence the human genome (see the previous review in Bios magazine), and has invested heavily in technology to speed up the sequencing process (at a cost of more than \$200,000,000 a year - this is more than was spent on the Apollo space project!). By 1989, the ability to sequence had grown such that it would take a "mere" thousand years or so to sequence a human genome. Presently, in 1998, this same task would take about 50 years, and within a year or two, it is possible that one could read the entire DNA sequence from a single human cell, in perhaps a few hours!

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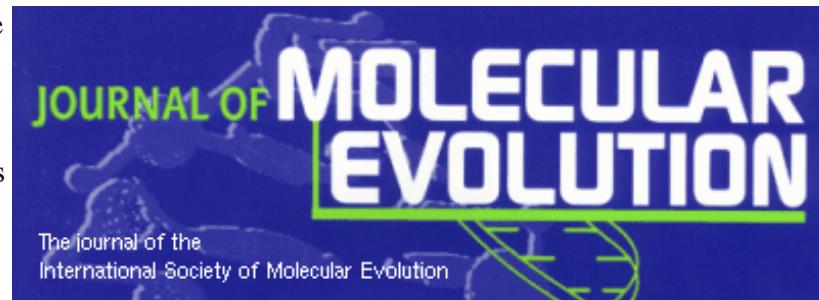
But the problem is, what will we do with this information? Currently, we don't even know for sure how many proteins are made in humans - nor are we really sure how to figure out exactly where the genes start and stop. But even if we were to know the SEQUENCE of all the proteins, it is still very difficult to figure out the structure and function of these proteins. For example, we have known (some of) the sequence for the gene that causes cystic fibrosis, for nearly 10 years. The full DNA sequence for this one single human gene is larger than the size of the ENTIRE genome of many bacteria! Presently, the best evidence is that this gene codes for a protein which is a chloride channel, or perhaps regulates a channel, but we still aren't sure of the structure nor do we know exactly how this protein works. We probably know more about the bacterium *Escherichia coli* than we do any other organism - and yet when the complete sequence was published last year, about a third of the proteins were known, a third had been postulated to exist, and the remaining third was totally unexpected - we're not even sure how many of these are "real"! In my opinion we understand such a tiny fraction of the wonders of life. We're not even sure how many genes humans have - nor is it even completely clear how we will be able to figure out where all the genes are! We still have a long way to go, a lot more to explain. So I don't think we've "uncovered the secrets of the cell" yet - a few perhaps, but certainly not even the majority. Once we understand our present state of ignorance, it is a bit more forgivable to see that people haven't proposed in detail the evolution of these complex systems. Please - give us a chance to define the systems well enough to know what's there, before we worry too much about explaining molecular evolution in gradualistic, step-by-step detail!

- He **UNDERSTATES** the vast amount of literature on molecular evolution that can readily be found, through simple searches. For example: "**Molecular evolution is not based on scientific authority. There is no publication in the**

**scientific literature - in prestigious journals, specialty journals, or books - that describes how molecular evolution of any real, complex, biochemical system either did occur or even might have occurred.**

(page 185). In the five specific examples of "irreducible complexity", I entered the search terms suggested, and came up with several hundred articles about the evolution of these systems, in a matter of a few minutes. Once again - please don't take my word for it - have a look for yourself! As far as books go, I have a book called "Molecular Evolution", by Wen-Hsiung Li (Sinauer Associates, Inc., Publishers, Sunderland Massachusetts, U.S.A., 1997, 487 pages). This book is all about molecular **mechanisms** of evolution, which includes a section on "Concerted Evolution of Multigene Families", which provides detailed specifics of the evolution of biochemical systems. Perhaps another good book along these lines would be "[Molecular Biology and Evolution of Blood Group and Mhc Antigens in Primates](#)", which deals with one of Behe's specific examples of irreducible complexity (this is only one of several books about evolution of the immune system). Go to [Amazon.com](#) and type in "Molecular Evolution" and see what you can find. Try [PubMed](#) for research articles on specific topics. The truth is out there.

Behe is quite critical of the Journal of Molecular Evolution, because most of the articles (85%, he reckons) deal with analysis of biological sequences, and hence somehow don't REALLY deal with evolution. However, as



I've stated above, evolution can be thought of as merely selection for a change in the DNA sequence. So by this definition of evolution (which by the way is a very good "working definition" in that it consistently yields good results when tested), if one wants to understand evolution at the molecular level, it makes PERFECT SENSE to look at tiny changes in DNA sequences, which could result in changes in the amino acid sequence of proteins, which could affect their shape and hence their structure and function. I just had a glance at this week's issue of J.Mol.Evolution, and found two articles dealing with the evolution of the immune system, and an article about the evolution of the eye. All three of these are from areas of "irreducible complexity", where scientists have allegedly not been publishing. PLEASE, don't trust me - click on the link and check it out for yourself!

I think Behe also understates the evidence for good old-fashioned Darwinian evolution, at the organismal level: "...**As a result, evolutionary biology is stuck in the same frame of mind that dominated origin-of-life studies in the early fifties, before most experiments had been done: imagination running wild. Neither of Darwin's starting points - the origin of life, and the origin of vision - has been accounted for**

**by his theory. Darwin never imagined the exquisitely profound complexity that exists even at the most basic levels of life."** (page 173). First, I don't think that it is fair to say that hardly any experiments had been done before the 1950's, or to imply that evolution is based purely on imagination. Second, there's been a considerable amount of literature on both the origin of life and the origin of vision. This is more Behe's OPINION that Darwinian evolution doesn't account for these two points. I would encourage the curious readers to check out Richard Dawkin's "The Blind Watchmaker", (or "Climbing Mount Improbable" or "River Out of Eden") and decide for themselves. Also, there's a quite [good article by a Swedish group](#), in which the gradual, step-by step evolution of the eye is considered in detail. Finally, and more to the point, the complexities of biochemistry are not that much greater than the complexities of organisms. Just think about the numbers - there are 30,000,000 different known, categorized species, but it is very likely this number is less than 1% of the total species that exist in nature. Darwin's theory of evolution was such an accomplishment because it allowed a simple explanation for how all this diversity and complexity has arisen, and continues to arise. His "explanation" was natural selection - which is a mechanism that has been tested and found to work experimentally; evolution by natural selection has enormous explanatory powers about the origins of life. Yes, it is true that Darwin didn't fully understand HOW this mechanism worked, but - and here is where I beg to differ with Michael Behe - we DO understand now the mechanisms by which evolution work, at the level of molecular genetics, as for example the evolution of the eye. But this does not at all counter the evidence of evolution from numerous observations at the species level. Over the years, I have accumulated [my own personal library of evolution/creationism books](#), with more than a hundred books on documented examples (and possible mechanisms) of biological evolution. I think that it is quite true that biological systems are indeed very complicated at the organismal level, but it's also true that "nothing in biology makes sense except in the light of evolution" (Theodosius Dobzhansky).

- Finally, in my admittedly biased opinion, he **SETS UP A FALSE DICHOTOMY** - if there are indeed complicated systems that scientists can't presently explain the origins of, then **it must be** that there was a "Great Designer" who is responsible. Hidden in this argument is the idea that if we CAN explain the origins of life, then there is no need or reason for the existence of God. This sounds a bit like the "vitalist" theories of the past, which held God is what we don't understand. I can choose to look at the wonders of nature and believe in God or not - but I don't feel that I am necessarily FORCED to believe or not to believe. I have a choice in the matter. I get the feeling Behe thinks we DON'T really have a choice - that anyone with half a brain who sees how complicated biochemistry is, MUST believe in a Creator God.

Another type of false dichotomy is the idea that one has to choose between Darwinian Gradualism or Intelligent Design. I think there are (at least) two other alternatives here:

- **punctuated equilibrium** - periods of stasis, followed by rapid

change (as proposed by [Stephen Jay Gould and Niles Eldridge](#)). There is growing evidence that evolution happens in short bursts of creativity, rather than exclusively by gradualism. Behe mentions this (on pages 27-28), but somehow doesn't consider it as an alternative to gradualism in his discussion of "Intelligent Design".

- "self organized criticality" - which comes from an interdisciplinary approach from physics, math & biology, by people such as [Stuart Kauffman](#), [Per Bak](#), and [Brian Goodwin](#). Although he never mentions work by the latter two, Behe dismisses Kauffman's ideas as "**too mathematical**" (page 30), "**fact-free science**" (page 156), "**he doesn't discuss biochemical structures**" (page 178), and finally he concludes that Kauffman's theory "**requires preexisting, already functional systems**" (page 192). But Kauffman points out that in his system you DON'T even need DNA or RNA or protein, but rather the "roots of life" lie in catalysis itself and in the combinatorics of chemistry. I encourage the reader to have a look at the chapter "Order for Free" in Kauffman's "**At Home in the Universe**" - where he discusses at length (as he does throughout the book) that what he finds is the emergence of order from chaotic systems - this order can spontaneously appear - from "nothing". The only requirement is that the system be far from equilibrium. I am presently using this "fact-free science" to model protein structures [e.g., BIOCHEMICAL SYSTEMS], and have found great insight and usefulness provided by this theory.

I believe it is likely that in reality, a combination of all three possibilities - gradualism AND punctuated equilibrium AS WELL AS self organized criticality could be necessary to account for the evolution of complex systems. In fact, there is an excellent chapter in Per Bak's recent book "How Nature Works - the Science of Self Organized Criticality", (Oxford University Press, 1997) where he models how gradualistic evolution (e.g., natural selection of small changes) can result in periodic, wildly non-linear punctuated equilibrium. There has been more than 2000 papers published about self organized criticality, making Per Bak's original paper, published in 1987, "the most cited paper in physics during that period".

One could cite individual examples of evolution by each of these three - my point is that it is not a simple "if gradualism is wrong, then intelligent design is the only logical option available". It is not at all that I am opposed to the idea of "intelligent design" - but this is a theological statement, and not that much different from saying "then a miracle happened". Yes, miracles happen - but these must surely be beyond the realm of science! For that matter, I'm not sure that I understand Behe's problem with Stuart Kauffman's emergent properties - this is essentially the same interpretation as the Talmud

- even held a thousand years ago - that Genesis is about God creating order from Chaos. Why shouldn't this be considered as an alternative (or even God's method of) "Intelligent Design"?



I have heard some people complain that Darwinian theory has kind of become some "dogma" that scientists are simply not willing to give up. Am I giving such a strong defense of an attack against the "orthodoxy of Evolution" for this reason? It is not really that I am trying to defend Darwin's theory of gradualism. In fact, I think gradualism is inadequate, by itself, to fully explain the origins of complexity. As in the case of the origin of domestic wheat - nature made leaps (at least) TWICE with the addition of complete genomes. So yes, this is a clear breakdown of "gradualism", and it happens in many other well documented cases. Could God have been responsible for these leaps? Sure - but why not say that God also uses evolution? Why limit God to using only "non natural" methods? Furthermore, I personally find the wonders of life a reflection of intelligent design, by God, even!. But I base this on my own private faith, and not on scientific reasoning. Finally, I think there's some truth to Stuart Kauffman's idea of emergent properties (look for a review of Kauffman's book in an upcoming book review in Bios magazine!). Darwin himself realized that gradualism was likely not going to be the ONLY mechanism for evolution. Of course, science cannot explain EVERYTHING and give meaning and purpose to life - nor should it! I readily admit the limitations of science, and often warn my students of the dangers of reductionism. A recent survey reports that 40% (I'm quite skeptical of the 90% that Behe claims on page 239) of the scientists they surveyed believed in God - a "personal God" that they could pray to. In my own experience, 40% sounds reasonable - I know many scientists who DO indeed believe in God, and many who don't. But this is probably true across the population in general. Science doesn't have all the answers - nor do we really CLAIM this. My own personal feeling is that people who use science to "prove" their atheism are equally guilty of distorting science.



In many senses "**Darwin's Black Box**" has a flavor which is similar to many of the more traditional creationists books - an appeal to ignorance of the subject matter. To someone who knows only a little bit about biochemistry, (indeed, the intended audience) this book could sound like a devastating attack on Darwinian evolution by natural selection. Unfortunately, it was quite tortuous for me to read. The subject matter has the POTENTIAL for a very good book, but I was continually frustrated by his distorted portrayal of molecular

biology. It is my own opinion that, upon closer inspection, his "**biochemical challenge to evolution**" vaporizes to essentially a restatement of the traditional creationist attack on Darwinian gradualism: life is so complicated - it HAS to have been created by a divine intelligence. This is a matter of belief, either I can choose to believe that God created life, or I can choose not to believe this - but to say that science FORCES me to believe one way or the other denies my free will. "**Inferring that biochemical systems were designed by an intelligent agent is a humdrum process that requires no new principles of logic or science**" (page 193). Most molecular biologists would agree that many biochemical systems appear to be designed (*i.e.*, optimized energetically, as Stuart Kauffman has put it so well)- but they would argue that it is selective pressure from "nature" or the environment which is responsible for the design. For a scientist to say that "a miracle must have happened" is not a routine (or valid scientific) explanation.

[Link to a list of some more books I've read about science and religion.](#)



After I had finished writing this review, I read an essay by Manfred Eigen (from the Max Planck Institut für Biophysikalische Chemie, in Göttingen). I think the following quote is a good summary with which to end this response to Behe's "**Biochemical Challenge to Evolution**".

**"Molecular Biology has confirmed Darwin's fundamental idea through its ability to disclose what the genomes of living organisms have in common. Information, in this case genetic information, is formed by way of successive selection. Darwin proposed his principle for the evolution of autonomous living things. An extrapolation to pre cellular systems, to answer the questions 'How did the first life forms arise? From where did the first autonomous cell come?' seemed to him to be too daring a step. Once he did express a speculative 'if' and qualified it immediately with 'oh, what a big if!'. The exciting realization today is that selection is already active at the molecular level, with replicable molecules like RNA and DNA, and so is amenable to a derivation on the basis of the physico-chemical properties of molecules. This closes the gap which yawned between biology on the one side and physics and chemistry on the other. This does not imply that biology may be reduced to physics and chemistry in the conventional sense. It simply confirms that there is a continuity between physics, chemistry, and biology. The physical basis of**

living systems has its own characteristic regularities. It is a physics of information production.

The new theory of self organization goes far beyond Darwin in detail and answers questions that had to remain open or were even paradoxical in his time. Darwin's legacy is a testimony to the 19th century." (from "What is Life? The Next Fifty Years - Speculations on the future of biology", edited by Michael P. Murphy and Luke A.J. O'Neill, Cambridge University Press, 1995, page 11)



## 4. An Update (October, 1998)

What has happened in the area of biochemical evolution recently? According to Behe, there is embarrassingly little progress being made in the area of molecular evolution. So one might not expect much to have been found since his book was published in 1996. Of the approximately 4100 articles published on molecular evolution in the PubMed database (as of October, 1998), most (3471 or ~84% of the total) were published since 1996! I want to outline just 2 major advances in the last few months, and relate these findings to Behe's book.

The first discovery to be discussed is the finding of an RNA molecule that can catalyze nucleotide synthesis. (Unrau and Bartel, *Nature*, **395**:260-262, 1998.) This was done by a clever modification of natural selection in a test tube. The theme of chapter 7 in "Darwin's Black Box" is basically about the complexity of synthesis of nucleotides - in particular AMP. "**If there is a detailed Darwinian explanation for the production of AMP out there, no one knows what it is...**" (page 161). I strongly encourage the reader to take the time to have a look at this article, as well as the "news and views" article which describes the significance of this finding (pages 223-225 of the same issue (17-Sept-98) of *Nature*). Using a similar method of selection, other enzymatic activities for RNA have been found, such as an ester transferase (a postulated precursor to ribosomal RNA; *Chem. Biol.*, **5**:23-34, 1998).

The second major recent discovery has to do with the origins of the immune system. Again, Behe lays down the challenge: "**We can look high or we can look low, in books or in journals, but the result is the same. The scientific literature has no answers to the question of the origin of the immune system.**" (page 138). Now a clear, simple, molecular mechanism has been proposed: the immune system we know today could have arisen due to a single insertion of a transposable element. (A transposable element is a piece of DNA which codes for a protein which will then bind to the DNA loop the DNA around and splice out the DNA, and then the DNA mini-circle can be spliced into another location of the genome. Some types of transposable elements make a copy of the DNA first, thus duplicating themselves.) The RAG1 and RAG2 proteins are actually two halves of a transposase. These elements constitute less than 5% of the DNA in yeast, roughly a third of human DNA, and nearly all (>98%) of the DNA in lilies. In a real sense this is "selfish DNA", but actually this ability to make copies of itself and splice together different regions has been utilized (through natural selection) to develop the immune system. "One might argue that such complex organisms as mammals (and other vertebrates) can only exist thanks to an immune defense system whose repertoire matches that of invading viruses and microorganisms (many of which, incidentally, use DNA rearrangements to increase their antigenic repertoire). If that is true, we may owe our existence to one transposition event that occurred 450

million years ago..." (*Nature*, 394:718-719; 744-751, 1998). Once again, the reader is encouraged to seek out the original literature and read for themselves the detailed mechanisms proposed. My point here is merely to wave a flag and say that what Behe had declared impossible has been obtained!

These two examples are merely a small sample of the literally THOUSANDS of articles that have been published about the details of molecular evolution in the past two years. It is important to bring up these examples, because this shows a real weakness in the logic that says "we don't know how this happened, so God must have done it!" What happens when someone calls your bluff and actually DOES provide a step-by-step mechanism for the gradual evolution of the immune system?

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## 5. Is Intelligent Design Science? (August, 2000).

Since I wrote this review more than 2 years ago, I have received hundreds of emails from people about the web page. Very roughly, about 10,000 people have visited the sight, from about 5000 different computers (e.g., unique IP addresses), located in more than 60 different countries.

Several people from the "Intelligent Design crowd" have written to me that I truly did miss the point about what makes a flagellum irreducibly complex. (Hey, I said I was uncertain what was meant in this section!) These Behe manuscript scholars have pointed out that in fact what Behe REALLY means when he says that the flagella is "irreducibly complex" is that you need all three components - that is, microtubules, connectors, and a motor. So all Behe MEANS when he shows this picture of a cilium and says it's really complicated with more than 250 proteins, is merely that you need each of the three components, all functioning together. He is NOT saying that the cilium referred to in the picture is "irreducibly complex". Well, O.K., I guess he IS saying it's "irreducibly complex", but you don't need all of the components - just the three different functioning groups. So you might in principle find a flagella with only 3 proteins - one for each function - but the "irreducibly complex" refers to the FUNCTION, not the components.

O.K., I guess, but I still maintain that it is certainly easy (and reasonable) for one to conclude from Mike Behe's drawing of the cilia with all its complexity, that THIS is what he is saying is "Irreducibly complex", especially when he says that

you need ALL the parts to function. But no, in fact you can have cilia with considerably fewer parts, which are still "Irreducibly Complex". Is it just me, or is it common for people to think that Behe was actually meaning the cilium in the picture when he says it is "irreducibly complex"? Wouldn't it seem reasonable to think that Behe was saying you need all 200 (or however many proteins) of the cilium for it to function? At least that is what I thought the first time I read the chapter. But when I find cilia with fewer parts (proteins, I was thinking), they are STILL indeed "Irreducibly complex". And in fact, some of the "Irreducibly Complex" components are themselves "Irreducibly Complex". Kind of like Russian dolls, I guess. (Some creationists have proposed that ecosystems, individual animals, cells, metabolism, in addition to Mike Behe's complex biochemical systems, are also "irreducibly complex".) So how are we supposed to understand this in terms of a machine where we don't know the exact number of parts? Wouldn't it help to try and be a bit more quantitative here, rather than saying "we need somewhere around 3 to 8 pieces for this irreducibly complex mousetrap"? Maybe you need 8 parts, but maybe you can get by with 3 - we don't know yet. Why not just say something simple, like "we need at least 26 proteins for the bacterial flagellum to work"? I asked this in the discussion forum. "Mike Gene" replies in the ID discussion forum that he thinks that being quantitative about the number of proteins is a good idea, and in fact they are trying to come up with firm numbers. If anyone is interested, they can visit the discussion at the following URL:

<http://www.arn.org/ubb/Forum1/HTML/000203.html>

So the ID crowd is not sure exactly HOW MANY proteins are necessary even for a flagella, but they KNOW it is "irreducibly complex", whatever the number of proteins turns out to be. Maybe 26, they say. Fine, but I think if you want to talk science, let's try and get some numbers here, for simple minded people like myself to try and get a grip on what they are really talking about, and also to allow people to hold them to their predictions. (Hey, this happens in science - you have to be willing to stick your neck out and see if other people can validate or falsify your work!) The problem is that no one knows how many proteins are required (yet). Hmmmm. Sounds like perhaps it is a bit premature to be making such bold claims about something that hasn't even been fully defined yet!

Note that the topic of this group is "Is Intelligent Design Unscientific?" (As opposed to the more simple question: "Is ID Science?") This is run by the ID group, so the ball is in the court of anyone who wants to try and show why ID is NOT unscientific. Kind of an interesting twist. But I have stated in this forum why I think that ID is not science, and that is because it is often motivated by religious convictions, makes no useful predictions, and has never been published in a peer-reviewed scientific journal. It turns out (once again) that I was WRONG on this - again, two different people have given me examples of how ID has helped them to make predictions to test in the laboratory. Fine. I'm willing to accept that - now, could someone please try and convince me that the belief that "something is soooooo complicated that God must have made it" really qualifies for science?? Look, I'm even willing to consider a couple of nice articles about ID published in the scientific literature - has anyone published about this?

Well, it turns out that someone actually HAS published an article about ID - in [The Journal of Theoretical Biology](#) - and that "someone" is me! I was surprised when someone wrote me an email, saying the article by Richard Thornhill and myself, on "Darwinian Mechanisms in Evolution" actually supported the view that Intelligent Design should be taught as an alternative to Evolution a high school in Kansas. Surprised is putting it mildly. Actually, in addition to the email, this happened (at least) twice - once in a Kansas discussion group, and once on a web page (which has since disappeared) which linked to a review of our article by "Mike Gene" (a pseudonym for someone who claims he is NOT Mike Behe). You can read our [actual published article here](#), and ["Mike Gene's" editorial version of how I had contributed to ID" here](#).

"It's official. Behe's concept of irreducible complexity (IC) has found itself in the peer-reviewed scientific literature..." begins "Mike Gene's" editorial. The point is that the purpose of our article was to show true Darwinian alternative mechanisms which could explain Mike Behe's "Irreducible Complexity", and that ID was NOT one of those mechanisms (as stated explicitly in our [J.Theor. Biol. article](#)). However, we DID indeed site Mike Behe's book, and so now we have actually "helped ID" get into the scientific literature. (?) All I have to say is that if someone thinks getting trashed is good recognition, then they don't understand science. Maybe "getting your name out" is good in politics, but one's reputation is important in science, and to be debunked does not mean that your idea was

necessarily "scientific". Yes, I agree with Mike Behe's premise that the origins of complex systems is difficult if not impossible to explain in terms of gradualism, but I strongly disagree with his conclusion that "God did it".

But what's worse is that someone in Kansas was trying to use our article to try and say that ID is therefore "scientific" and should be taught in the public schools. See more on this [below](#).

I have just had a look through PubMed, and found a rather interesting trend. If I were to look at the number of articles published with the words "molecular evolution" as a phrase in the abstract, I get the following numbers:

YEAR	"Molecular Evolution"	"Irreducible complexity"	"Intelligent Design" and evolution	evolution and "complex biochemical system"
1980	10	0	0	0
1981	13	0	0	0
1982	12	0	0	0
1983	8	0	0	1
1984	14	0	0	1
1985	24	0	0	2
1986	32	0	0	3
1987	43	0	0	3
1988	36	0	0	2
1989	40	1	0	0
1990	52	0	0	5
1991	39	1	0	1
1992	45	0	0	1
1993	56	1	0	2
1994	114	0	0	1
1995	322	0	0	2
1996	944	0	1	3

1997	1264	0	1	3
1998	1592	1	0	3
1999	1800	1	0	10
2000	726	0	1	2
Total	7555	5	3	53

note: the last entries are through July, 2000, and "total" represents the total number of hits in PubMed, which is a database containing references to more than 11 million articles. These numbers will change with time. Please have a look for yourself at the following URL: <http://www.ncbi.nlm.nih.gov:80/entrez/query.fcgi?db=PubMed>

I would strongly encourage the interested reader to have a look at the database and convince themselves whether there are indeed ANY articles published in the scientific literature where "Intelligent Design" is considered to be a legitimate scientific option for explaining the evolution of complex biochemical systems. It is somewhat ironic that despite Mike Behe's claim, there are several articles describing the evolution of these systems, yet I haven't found any yet that ref to HIS "scientific theory" of Intelligent Design, out of more than 11 million articles.

Hey, but I'm only human, and certainly can make mistakes. If anyone knows of ANY article published in the scientific literature, where Intelligent Design is used as a scientific explanation for evolution, please email me ([Dave Ussery](#)), and I will post it on the space below.

So far, as of 7 August, 2000, there have been 0 replies....

When I debated Mike Behe in November, 1998, I brought up the fact that there were several more articles published about molecular evolution than he implied in his book. His reply was that he used a different database, and that since most of

the book was written in 1995, of course it would not be reasonable to expect him to catch any articles published since then. Fair enough, I suppose. However, please have a look at what has happened since 1995, in terms of the number of articles published about molecular evolution. I am sure this is in large part due to the explosion in sequence information (presently, GenBank is doubling every 6 months - but this is not a constant rate, and in fact it will probably double AGAIN in 5 months....). But having said that, I still maintain that it is extremely dangerous to build up one's case on the lack of published literature, especially in a field such as this! Yes, it is true that probably many (maybe even MOST) of these articles do not deal with the molecular evolution of complex systems - but with the volume of articles being published (more than 7000 so far!), I cannot rule out that something has not already been published - nor can the growing numbers in the "Intelligent Design" crowd of Mike Behe's followers! It is simply not possible to read ALL of these articles. Such bold statements as "no one has EVER published an article about the molecular evolution of a single complex biochemical system" seem to be asking for trouble. So I might ask a similar question - has anyone EVER published an article showing that Intelligent Design is a scientific alternative to Darwinian evolution?

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Recently, Mike Behe has published on the web a set of five articles in "response to critics". However, since two of the articles are directed to other scientists, and are about different topics unrelated to my concerns, I will focus here on only three of the articles.

1. In "Philosophical Objections to Intelligent Design: response to critics", Mike states clearly in the first paragraph, that some people define 'Intelligent Design' as merely meaning that "*the laws of nature are designed to produce life and the complex systems that undergird it*". But then he goes on to say "...let me just say that that is not the meaning I assign by the phrase. By 'intelligent design' I mean to imply design beyond the laws of nature." So now he has defined it pretty clearly, for all to see. Notice that he is saying that ID means something that is

"beyond the laws of nature". [But he claims this is scientific??]

However, towards the end of the document (on page 8 of the printed version on A4 paper), he switches gears, and NOW says essentially what he said in the introduction was NOT his point of view. Maybe I'm reading him wrong again, but here's the quote, and I'll let the reader decide what he's trying to say here...

*"I should add that, even if one does think the designer is God, subscribing to a theory of intelligent design does not necessarily commit one to 'miracles'. At least no more than thinking that the laws of nature were designed by God--a view, as we've seen, condoned by the National Academy of Sciences (National Academy of Sciences 1999). In either case one could hold that the information for the subsequent unfolding of life was present at the very start of the universe, with no subsequent 'intervention' required from outside of nature. In one case, the information is present just in general laws. In the other case, in addition to general laws, information is present in other factors too. The difference might boil down simply to the question of whether there was more or less explicit design information present at the beginning--hardly a point of principle."*

*"Now one can't have it both ways."* He says. I agree. O.K., I admit I took this quote out of context. What Mike Behe is referring to here is that some people try and falsify his irreducibly complex systems, while at the same time say that intelligent design is not falsifiable. I was accused of doing this in the discussion forum. An example I thought of is as follows - imagine that someone claimed that God was giving them visions of the future. Now I ask them to tell me what the colour of the next car that was to come through the intersection - and they were to say "blue". I would try to falsify their statement - but that certainly does not mean that I think their presuppositions were true. The same goes for intelligent design. Yes, you can make some statements which are testable, but that does not mean that the system is falsifiable, because everytime someone tries to falsify the statement, the bar gets moved up a notch. How can someone DISPROVE that God did NOT do something? Can one put God in a test-tube?

I was somewhat surprised to find that Mike Behe mentioned my web review of his book (e.g., THIS review!) - but he never talks about our article in J. Theor. Biology, where we discuss three other mechanisms, WITHIN THE BOUNDS OF SCIENCE, which could explain the origins of complex systems, as alternatives to step-by-step gradualism. Why doesn't he at least reply to my criticism of his book which is published in the scientific literature? Behe points out that I misunderstood what he meant about how many proteins are necessary for flagella - but I said I wasn't sure on this - I hedged in the review I wrote 2 years ago, and have now stated clearly, for all to see that I was wrong here - see the top part of this discussion. Fair enough, I guess - he's right on this point. I misunderstood him. However, I still don't agree with him on the future of science....

*"Because no one can see the future, science has to navigate by the data it has in hand. Currently there is only one phenomenon that has demonstrated the ability to produce irreducible complexity, and that is the action of an intelligent agent. It seems to me that that alone justifies pursuing a hypothesis of intelligent design in biochemistry..."*

All I can say to this is, have a look again at the data in the table above. It looks like to me that there are indeed articles being published about the molecular evolution of complex biochemical systems. Mike Behe just chooses to ignore them. But as I keep saying - don't take my word for it, please have a look for yourself and decide based on the evidence you find.

2. In a different web page, Mike Behe complains that some journal rejected his manuscript on his "reply to critics of Intelligent Design", so this shows there's some sort of conspiracy out there. [He has even published the correspondance, including the rejection letters on a web site.](#) Look, our J. Theor. Biology manuscript was barely accepted the first time, and the referee was pretty hard on it, and made lots of suggestions of what he thought was lacking with it. So we

worked on it, and resubmitted it, and it eventually got published. Out of the 6 articles I have had published so far this year (in the year 2000), only 2 have been accepted as they were, without revisions. One of them I submitted to *Nature* magazine, because I was convinced this was a really big finding - that based on periodicities of DNA structures, we could show that about one-fourth of the genome had been fairly recently acquired from an Archaea - which is quite different from bacteria, in terms of phylogeny. We even have a good candidate of what genus the Archaea was - but the editors from *Nature* said "no", so we submitted to another journal, and THEY said "no", and then we went for *Nucleic Acids Research* and they finally published it. The only reason I'm telling this story is that this kind of thing happens often. And sometimes even very good, nobel prize winning articles wind up getting published in obscure journals. Yes, sometimes editors make mistakes as well. If Mike Behe REALLY feels that he has a good case, why not try another journal, instead of whining and complaining about it in front of everyone? Or for that matter, why not take up Ken Miller on his challenge to a debate at the next meeting of the International Union of Biochemists or why not get someone to submit a poster to any one of dozens of scientific conferences held every year? The chances are there, why not take them? It's been four years since this "wonderful idea" of intelligent design was proposed - that's plenty enough time to get something published somewhere, in the scientific literature, I would think.

3. Finally, in his web page "[Irreducible Complexity and the Evolutionary Literature: Response to Critics](#)", Mike Behe tackles the problem of literature (or lack thereof) about ID as well as literature (or lack thereof) about evolution of complex biochemical systems. Yes, I agree with him that the PubMed literature search will give you lots of articles that maybe you don't want. That's why you have to go through them and have a look. Behe said he had a look at the articles, and there's nothing there. I would once again invite the curious reader to have a look at the [table above](#), and try for themselves - in particular, type in the following key words, and see what you can find: "evolution complex biochemical system". I found 53 articles, many of them exactly what Behe claims are not there - but please, have a look for yourself!

## 6. Should ID be taught in U.S. public schools?

This is a bit of a digression from this book review, but since some people want to use Mike Behe's book as a text in high school biology classes, I thought I might bring it up here. You can follow [a discussion of this at the ARN research network](#), if you want to see the reaction of some of the ID people. I just put it up, but I am willing to predict that SOME of the ID crowd (including Mike Behe) are not that thrilled about replacing ALL of evolution with ID. So I guess I'm expecting kind of a mixed reaction. (Or maybe no one will even reply to the posting!)

Let me get this straight - the "Intelligent Design" people are saying the following:

1. Gradualism cannot fully explain the origins of complex biochemical systems.
2. Therefore, it is reasonable to propose that an "Intelligent Something" created them *de novo*, using laws outside those currently observable within the bounds of science.
3. No paper has appeared in peer-reviewed literature on this within the scientific literature (out of more than 11,000,000 articles in PubMed!).
4. Intelligent Design is a "new movement" within science.
5. THEREFORE, ID should be taught in public schools as a logical alternative to nasty ole' Darwinism.

The proponents make these claims with a straight face, and I suspect they really do believe what they are saying, but the bottom line is that this is really no different than creationism, and in my opinion should NOT be taught in the public schools as SCIENCE. I certainly agree with point number 1 - that was the purpose of our paper in J. Theor. Biology. However, how can we teach something that says "this is sooo complicated, God (or an "Intelligent Something") must have created it"? This is just simply not science. The ID crowd admit they have not had anything published yet, but they are working on

it, and since it is difficult to get their stuff published as science (see above) are considering setting up their own journals, perhaps like the "young earth creationists". About a week ago Phil Johnson appeared on "Nightline", and when asked whether in fact ID was nothing but a rehash of Paley's arguments from the 19th century, replied that he thought in fact ID was MORE than 200 years old - that the idea of Intelligent Design goes back more than 2000 years ago! So even one of the main proponents of ID is saying it is not really anything "new". So perhaps they should try and sneak ID into a HISTORY class rather than pretend it is "cutting edge" science!

Once again, just for emphasis, in my opinion, if something has never been published in the scientific literature, and employs essentially a supernatural explanation (well, we can't understand this complicated system so an Intelligent Something must have created it *ex nihilo*), this should NOT be taught in the public schools as SCIENCE. In a real sense, I have a hard time differentiating between the more generous form of Intelligent Design (as proposed by Phil Johnson) and that of the Creationists. In fact, many of the creationists arguments employ "Intelligent Design" as part of their main supporting evidence for creation by God. See for example, [my review of "In Six Days - Why 50 Scientists Choose to Believe in Creation"](#).

I can almost hear some of the ID people whining that in fact they are proposing something that is not religious at all, and is merely an alternative route of evolution (again, see the ID discussion forum for more on this). They might say that it is ridiculous to rule out evidence by preconceptions - for example, imagine the police investigating a murder, but not being allowed to investigate the knife in the victim's back, because only "natural causes" are considered "scientific". (The creationists often invoke this type of an argument.) Come on, let's not make scientists look like a bunch of idiots blindly attached to their presuppositions. Yes, it is certainly true that science doesn't deal with something that is supernatural - how can it? I am not saying that something outside of nature cannot happen - but merely that it is beyond the bounds of science to investigate it. Sure miracles can happen, but I don't think a discussion of miracles belongs in a science class.

To say that an "Intelligent Something" created an amoeba 3 billion years ago, with all these "irreducibly complex" features (as Mike Behe discusses in the conclusion of his book) is an interesting idea, but it is not within the bounds of science. Nor should it be taught in the schools as science. In all fairness, I think Francis Crick's similar idea

that the earth was seeded with bacteria from space aliens should also not be taught as part of the evolutionary theory within science class - this is again an interesting idea (not that different, really, from Behe's amoeba), but does not really offer any scientific explanation, in terms of mechanisms of how evolution occurs.

Finally, I have recently read "The Triumph of Evolution, and The Failure of Creationism", by Niles Eldredge (W.H. Freeman and Company, New York, 2000). Eldredge says that what we teach our children about science in the schools is very important. I agree with him:

*"We will not go very far if we pretend to teach our kids that we cannot tell the difference between real and phony science. Yet that was the gist of all those 'equal time' laws in the 1970s and 1980s: the Arkansas and Louisiana legislatures were actually telling the teachers in their public schools to pretend not to know the difference between real science - flaws and all - and outmoded or simply bad science. I cannot imagine anything more perverse, more deliberately harmful, than teaching kids that their elders cannot tell the difference between the real and phony. Some of them, of course, cannot. But all but the relatively few creation-leaning science teachers throughout the fifty states most assuredly can, and requiring them in essence to lie to their students sends about the worst message imaginable to the younger generation. And kids, of course, can see right through that." (page 152)*

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About the author: David Ussery is currently an associate professor at the [Center for Biological Sequence analysis \(CBS\)](#) in the Institute of Biotechnology, Danish Technical University, in Lyngby, Denmark. He grew up in Arkansas, and claims that by the age of 14 he was an ardent Creationist. However, by the time he got his B.A. in Chemistry at [William Jewell College](#), he was convinced that perhaps the creationists didn't have ALL of the answers. He went on to get an M.S. in [Chemistry at the University of New Mexico](#), and then started work on his Ph.D. in the [Department of Biological Chemistry at the University of Cincinnati College of Medicine](#). By the time he graduated (6 years later), the department had grown substantially, merged and changed its name to the "Department of Molecular Genetics, Biochemistry and Microbiology", reflecting the explosive growth in this area. He then did a post-doctoral fellowship in a [bacterial genetics group at the IMM, University of Oxford](#), followed by a year in a bacterial [pathogenesis group in Oslo, Norway](#). He taught [Genetics and Biology for non-majors](#) at [Roanoke College](#), in Virginia during the 1997-1998 academic year, before finally moving to Denmark, where he enjoys doing research, reading and thinking about molecular evolution, and paying taxes! His current area of research is exploring the role of DNA structure in bacterial chromatin.

## Links to other reviews of this book:

- [This same review, with an "irreducible mousetrap" background.](#)

- [Link to text only version.](#)
- [Bios magazine \(vol. 70, pages 40-45, 1999\)](#)
- [ENSI version, with Introduction and comments by Larry Flammer](#)
- [Amazon.com\(March, 1999\).](#)
- [Barnes& Noble \(May, 1999\).](#)

## Irreducible Complexity Demystified (May, 2003).

## A web site on the Evolution of Flagella



[Go to Dave's Evolution page](#)

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