The case that mammalian intelligence is based on sub-molecular memory coding and fibre-optic capabilities of myelinated nerve axons

By R. R. Traill

Originally Published (1988) in
Speculations in Science and Technology, **11**(3), 173-181.
Republished online (June 2009) by
Ondwelle Publications, Melbourne — and by *Gen.Sci.J.* — with permission from Springer Verlag

Preface to this 2009 re-issue

This paper has served as the 1988 **midpoint-review** of a rigorous ongoing investigation into Brain-and-Intelligence. This project has been guided by the notion that *having a coherent set of well-defined theories* is just as important as the related labwork, and that theoretical progress requires attention to detail — especially the *micro*-detail, and with some emphasis on explaining anomalous findings. That has led to (i) building upon Piaget's account of intellectual development (based on biological and Darwinian mechanisms); (ii) using interdisciplinary knowledge to "redesign" *plausible* biological mechanisms apparently-capable of achieving such self-education tasks unaided; and (iii) exploring the theoretical consequences of such mechanisms — some of them branching into other disciplines such as embryology.

That has meant swimming against the empiricist tide which dominated science for much of the twentieth century; but it is interesting to note that other theorists who emerge from that empiricist tide, have occasionally come to similar conclusions via different lines of reasoning. E.g. compare: ♦This paper's *interest in infrared* stemmed from earlier arguments based on molecular energy levels and myelin geometry (and hence it cites findings of bio-emissions[48–51] merely as supporting evidence, without inquiring any further) — whereas ♦Other investigators such as vanWijk (2001 and earlier)[{57}] *started* from the bio-emissions and developed their theory on that basis instead, with no thought of myelin geometry. (And both works cite the same 1978/79 book[48] for some of their evidence).

It may be useful to note that *two* parallel streams of study have emerged during this project, and these will tend to interest two different types of audience. • Firstly there is the obvious field of Piagetian Psychology and Epistemology.[30,{58}]

• The second stream began by using an ensemble of Physiology/Physics/Infotech concepts to find *technically-plausible* micromechanisms for the storage and retrieval involved in the above-mentioned *advanced human thought*,[30,{58,59,60(ch8)}] — in contrast to the textbook accounts which still offer no comprehensive account of plausible micro-management of detail. However it was then necessary to go further to cope with some resulting logistical complications in *intercommunication*,[{61–63}] and in *growth-control*,[{60(ch7), 64}] etc.

The current text served as a convenient summary for both streams at "the end of the beginning" of this project, so it may be a useful starting-point for those investigating its arguments.

R.R.Traill, Melbourne, 30 June 2009.

CONTENTS

2009 page

The case that mammalian intelligence is based on sub-molecular memory coding and fibre-optic capabilities of myelinated nerve axons

R.R.Traill

Originally published (1988) in
Speculations in Science and Technology, Vol. **11**, (No.3), pages 173–181.
Here republished online, with the permission of Springer Verlag.

Recent annotations (© R.R.Traill, 2009) have been added,
offering some updates and relevant links etc.
without disturbing the original text or its line-formatting.
These recent insertions are identifiable below as:
(i) being footnotes indicated alphabetically, e.g.[E]; — *and/or*
(ii) text enclosed within curly brackets, e.g. {`new comment`}, — *and/or*
(iii) obvious anachronisms.

Received: November 1987

Abstract Knowledge-growth in science apparently requires a proper balance between two activities: • experimentation and • the search for wide-ranging self-consistency. (The latter seems to have been neglected and the present project aims to correct this imbalance). The case that the brain itself normally uses the same two criteria is reviewed and accounts of possible mechanisms underlying such activity are outlined. For this it is postulated that there is major quantum/digital information processing at the molecular level and some signal transmission at infrared frequencies (multiplexing with traditional millisecond "spikes" along nerve fibres). It is also shown that such an approach can account for some hitherto unexplained features of mental activity, including retrieval, "storage", teleology, sequencing, control and decentralization within the brain.

A special need for speculation in brain studies

In disciplines such as brain studies, nature does not readily yield up all her secrets to the experimental investigator, even in the long run. Of course, we do discover more details as time goes by, but we have little control over what gaps remain in our knowledge because such shortcomings are largely governed by the feasibility of this-or-that experiment. As one prominent theorist put it, when discussing his molecular-level theory: "we are not aware of any direct experiment which might have been done for this study".[1]

Of the gaps left in this patchy overall picture, perhaps the main ones are at the two extremes of scale: • our ignorance of the submolecular mechanisms and • our ignorance of the overall "philosophy" of the design. Both questions are particularly difficult to probe if we confine ourselves to conventional experimentation alone. So then, are we condemned to perpetual ignorance on such matters?

This raises basic questions of epistemology, *the study of knowledge and its acquisition,* both for individuals and also for a society in its scientific progress. There has been a longstanding philosophical battle as to whether experiment or rational-thought is the source of this knowledge growth;[2,3] but I shall take the view that *both* are needed together and in <173>[A] about equal measure.[4-6]

It follows then that I am optimistic about making major progress in brain studies even if experimental effort gives us nothing more than diminishing returns, provided that we can find sufficiently rigorous ways of developing our understanding at a theoretical level. In this speculative process, it is likely that we will get best results if we observe the following guidelines:

(1) Postulate specific mechanisms as close to the micro end of the scale as possible. If the resulting elements are sufficiently well defined, we may then be able to invoke the "hard sciences" in our logical considerations, thus giving us much greater scope for precision.

(2) Seek valid universal principles for the overall macro-organization; notably plausible mechanisms and techniques for control and information flow, plus some explanation for apparent teleology and purposiveness.

(3) Take account of the experimental findings in all relevant disciplines: simultaneously if at all possible. This implies rigorous self-consistency and is related to the concepts of "equilibration",[8] "closure" and "coherence".[3] (In practice, this seems to mean asking awkward questions about possible mechanisms and suggesting new mechanisms, whilst using "foreign" disciplines to veto many of the otherwise unending theoretical possibilities.)

(4) Beware of any approximations which could lead to unwarranted extrapolations. Technology legitimately abounds with such "near-enough" rules, but these can sometimes be totally misleading in our search for rigorous theoretical solutions, despite our lip-service recognition of the danger. [First, we can become careless about keeping track of our underlying assumptions, especially in interdisciplinary work (see the discussion about ref.7 and the two examples in Appendix A). But there are also cases where an approximation can miss the whole point; for example, if we idealize the orbit of Mercury to suit Newtonian physics.]

In passing, we might notice that Wei's above-mentioned theory[1] does fit this set of criteria quite well, so arguably it deserves more attention than it has so far received. However, this is not the occasion to pursue that question further.

Brain mechanism as seen from psychology

We have just considered epistemology at the social level. Now we will again encounter the same sort of knowledge-acquisition task, but as performed by the individual; and clearly it is the brain that somehow provides the mechanism in this case.

Here the theory and research largely sterns from the works of Jean Piaget,[8] leading to such key concepts as:

Learning requires some sort of *non-passive action* from the learner (a sort of continual *experimental* process); and

In learning (at least at the basic level), one tries to find mathematical "Group" properties amongst one's would-be concepts.[5,8–10] This "equilibration" amounts to a process of *theory development.*

[In both cases note the formal similarity to the social epistemological processes.]

[A] "<181>" signifies *"Here endeth the original page 181"* — etc.

Piaget himself says nothing at all[B] about possible underlying material mechanisms, but this question has been tackled speculatively elsewhere.[11–13]

In the latter accounts, Piaget' s element of concept formation, the "scheme", was assumed <174> to have physical embodiments; and it was tentatively suggested that there were *DNA/RNA-like linear encodings,* bearing in mind such work as Hydén.[14]

Furthermore it was postulated that there was a many-to-one relationship: with a coordinated *large population* of similar linear encodings corresponding to one item of effective "memory", as in genetics or immunology. [This contrasts to computer encoding where the storage is still as linear codes, but only one per item of memory if we ignore such things as parity checks.]

This mass population of ultra-micro encodings seemed to offer several advantages over the early post-war idea about what the unit of thought encoding must be. The prevailing view was that the fundamental unit was either the whole "neuron" nerve cell,[15-17] or else its synapses (input terminals from other neurons).[18] [Theorists were often careful to talk of the "formal neuron", which need not necessarily correspond to the actual neuron. Hebb, for instance, was quite happy to concede that this formal neuron could actually be a submolecular mechanism (personal communication, 1977).]

Linear molecule versus neuron model

Some advantages of the linear molecule model over the traditional neuron model are now outlined.[C]

Physically linear organization "in strings" implies a preferred sequence of action. It largely solves the ever-present problem of "What do I do next?" Note that such default sequencing greatly simplifies organization and control within computers and evidently in genetic encoding also.[19]

Some aspects of "memory" or intelligence are inherited ready-made as "reflexes", whether or not they survive through infancy.[20] This inheritance would be much easier to understand if the underlying coding were embodied directly in RNA-like molecules rather than in some sort of subsequent "wiring up" between nerve cells.

At maturity, neurons become incapable of dividing. This loss of mitosis is compatible with their chromosomes becoming involved in some other coding function.[D]

The decentralized "large population" hypothesis makes it easier to understand why there is comparatively little loss of mental ability despite extensive brain ablations.[21,22]

[B] Nearly true but not quite. Piaget did *briefly* raise the question of physical embodiment — in his book "Biology and Knowledge" (1967), as later detailed in Traill (2008: http://www.ondwelle.com/OSM02.pdf).{58} However that was a rare departure, accompanied by an admission that this was outside his area of expertise. In short, he seems to have offered no definite suggestions or opinions about this matter.

[C] For an early discussion of this comparison, see my 1975 letter to N.E.Wetherick (Traill, 1976/2007, Ch.III: http://www.ondwelle.com/OSM06.pdf).{59} The most recent discussion is in Traill (2008), *loc.cit.*[B].

[D] This loose speculation implying a new role for supposedly-idle DNA is probably superfluous, because there is now a much stronger case for seeing *RNA* in this memory-embodiment role: (Traill, 2008).[B] That is fortunate because some new complications have meanwhile arisen concerning neuron mitosis: [The supposed inability-to-divide was almost universally believed in 1988 when this paper was published; and technically this "mitosis-ban" may still be true despite the later findings that some neurons can be replaced, (Nottebohm, 2002).{65} The key question here is: "*How* are they replaced?" — • "By the supposed division of *adult neurons*?" (which *would* tend to kill the "other coding function" idea) • Or, as seems to be the case: "Via a sparse set of *uncommited stem-cells*" (which would probably not affect the argument either way).]

More importantly, the use of large numbers of micro-elements makes it feasible to invoke trial-and-error[E] on a grand scale, since we can then afford to "throw away" a large proportion of failures. This is consistent with Piaget's idea that trial actions of some sort will always precede learning; and closely parallels the now-orthodox view in immunology that the body contains a vast stock of trace-level antibody "keys" in case the relevant "lock" should invade, even though most of these "keys" are never used by that individual.[23,24] Of course, it also parallels the much more wasteful *Darwinian* trial-and-error.

"Teleology" can be accounted for in all these trial-and-error models. Thus, in the case of brain function, it seems plausible that we are constantly discarding the encodings for all sorts of dubious actions and thoughts; and even our "forward thinking" has already passed sufficient testing within our mental model of reality. However, for beings as complex as humans, such activity must apparently be organized in a series of hierarchies so that partial-truths may be saved as "subroutines" for future reference, (figuratively speaking).

See below regarding Ashby's work.[27]

Other paradigms

Another psychology-oriented speculation was put forward by Pribram and his colleagues,[25,26] suggesting that Lashley's non-localization of memory could be explained <175> by some sort of hologram procedure. This suggestion was strongly criticized by Willshaw *et al.*:[7] but their criticism was based on their seemingly reasonable tacit assumption that any such holograms would be using audio-frequencies. However, as we shall see below, such assumptions are open to question, and indeed the Pribram proposal can be made into a useful adjunct to the molecular-coding model. It does mean though that the Pribram model should be re-cast at a much smaller scale, using a much higher frequency.

Another very useful paradigm is offered by Ashby.[27] This approach shows how it is possible to design adaptable and economical self-learning system, and Ashby makes the case that nature does actually use this principle. Moreover, this approach to organizational design has since been used commercially.[28,29]

On this model, it is possible in principle to describe a series of increasingly sophisticated "intelligent" systems, be they natural or artificial. Such a series seems broadly compatible with steps in the *phylogenetic* evolution of intelligence, but it also seems to accord with Piaget's developmental stages *within* the individual.[13]

It is, moreover, possible to use such concepts (together with others discussed here) to suggest mechanisms for a whole range of psychological and psychopathological phenomena.[12,30] It is unlikely that an these suggestions will be wholly correct, but at least they do offer potentially testable hypotheses, and that is probably an improvement over the present unexplained "causal gaps" in accounting for the laws of psychology.[20,31]

Hard-science aspects

Given that there is a sophisticated chemical memory-storage system and that there is also an electrical communication system along nerve fibres, *what feasible interfaces could there possibly be between these two media?* In effect this means attempting a design task, using existing psychological, biophysical and chemical laws as our "rule book" and "task specification".

[E] This *"trial-and-error"* cliché is meant to imply *undirected randomlike* choice between possible courses of action; — and that accords with standard usage amongst cyberneticians and computer-theorists. Some readers have mistaken such use of the word "trial" as implying deliberate choice. Of course that is sometimes valid, but not in the present type of context (here involving mindless Darwinian elements).

In the nature of things, the finer points of this "specification" have to be gleaned from a variety of different disciplines and in a way which is almost impossible to plan in advance. One must simply try to piece together a montage based on whatever reasonably reliable and precise observations are available. Such a procedure does not fit neatly into the usual experimental paradigm, but eventually a coherent picture does emerge.

Moreover, some aspects turn out to be very similar to features of another independent model in a different field of biology: communication between insects.[32–34]

Both models were prompted by some aspect of micro-anatomical geometry which lent itself to the interpretation using non-trivial physics. Both analyses gave a more thorough account of some communication phenomenon (though in quite different areas), and *both postulated laser-like infrared signals.* In both cases, this approach has ultimately involved visualizing the electrical phenomena in terms of the more general field-theory (and hence Maxwellian optics) rather than just using the simplistic circuit-theory approximation.

[There has been comparatively little understanding of this "make-do" status of circuit theory, even though the superiority of field-theory has long been on record: Heaviside[35], based on Maxwell[36] and Rayleigh.[37] Even in modern electrical engineering, there was some neglect of this point until microwave technology became commonplace.[38] Perhaps then we should not be too surprised if circuit-theory is still the dominant approach in the biological sciences.]

Anyhow, in this case such field-theory considerations amount to assessing the problem in terms of fibre-optics, as follows. <176>

Clues to the infrared interpretation of nerve activity

Clue A: Waveguide considerations

A critical examination of existing explanations of "electrotonic" signal conduction down myelinated nerve fibres. Myelin forms an insulating sheath around segments of the fibre, with intersegment gaps called "nodes of Ranvier". Such sheaths stop the normal primitive chain reaction along the membrane (except at the nodes), but instead they do make possible a much faster mode of transmission: "saltatory conduction" of signals. This improvement is traditionally explained in terms of resistance and capacitance as an "electrotonic" phenomenon.[39,40]

However, the more rigorous analysis shows up an *additional family of possible solutions.*[41] In effect, this finding says that the myelinated fibre should be viewed as a micro co-axial cable, capable of conducting electromagnetic waves in the infrared range (see Appendix A):

This conclusion does not deny the simultaneous validity of the accepted "Kelvin cable" solution as far as it goes, but it does deny that it is the *only* solution. We can then envisage the nerve-fibre as capable of carrying a much greater *baud rate* than hitherto expected, including a potentiality to *multiplex* various signals simultaneously (a feature which any *commercially viable* fibre-optic system would now have).

The prediction of an infrared component also implies that any interface mechanisms could be quite different from any previously sought, which brings us to another clue.

Clue B: Quantum considerations in general

In retrospect, the most obvious clue lies in considering quantum frequencies. Any access to transmittable messages encoded in RNA-like molecules would almost certainly involve quantum jumps at same stage in the process. Moreover, one would expect to find their wavelengths to be in the *infrared* range: in keeping with the organic energy-level transitions which must surely be involved.

The underlying effects could be orthodox biochemical reactions involving electron exchange, with energy jumps of about 0.5 to 1.3 eV.[42] In terms of wavelength, this corresponds to a range of about 2.5 to 1 μm, which puts it in the near infrared.

However, it is more likely that the primary effects would be associated with modes of vibration within the molecular structure. Indeed, this is the very essence of infrared spectral analysis as described, for instance, by Alpert *et al.*[43] A more neurological account is given by Sherebrin.[44]

Some of the spectral bands appear in nearly every organic sample, so it is questionable whether they would be much use for selective signal channels. (For instance 3.6 μm for CH_2; or the OH bands at 3 and 7 μm). Commonly there is a comparatively absorption-free window between 3.9 and 6.6 μm (although the 5 to 6.6 part is affected by aromatic compounds), so maybe we should half expect any transmission to be in this region; and maybe we should look for not-too-common chemical groups which do respond to such frequencies?

As for how such excitations could affect memory; that is discussed speculatively in detail elsewhere,[30] but includes the notion that such states might serve as variable operators or "gates" affecting signal transmission along molecular paths. (Note the formal similarity to the Hebbian theory mentioned above, but now on a much smaller scale.)

A further complication is that the spatio-temporal pattern is seen as all important here, both for the signal volley itself and for the extended site which should selectively detect it. <177>

Clue C. Direct detection of infrared in unmyelinated nerves

Infrared radiation has been shown to emanate from active nerve fibres.[45] True this work was done using crustaceans, so the nerve fibres were unmyelinated; but this still shows that infrared can exist in a form capable of signal transmission, even if we were to suppose that it could not be used constructively until the evolution of myelin. [See Wei[46,47] for discussion of one likely cause of such radiation.]

Later work,[48,49] has shown that coherent photon emission, from the infrared to ultraviolet, is common in active tissue of many sorts, including cucumber! So there is ample scope for such emissions to be used constructively by any species that can effectively detect them. Indeed, Konev reported that yeast cells were able to synchronize their mitosis by means of ultraviolet photons.[50,51]

Note that infrared is very heavily absorbed by aqueous solutions, so it is no easy task to investigate it experimentally. Accordingly, we might expect a bias in the literature in favour of detected visible and ultraviolet photons and against detection of infrared.

Clue D. "Insulation" of signal-channels

Nerve fibres are often close packed. If they are to avoid mutual signal interference, they need to be "insulated" in a manner appropriate to the carrier frequency being used. For infrared signals we might expect: (l) possibly some form of reflection enhancement to help keep photons within the dielectric of their waveguides, see Appendix A; and (2) severe absorption for any that escape: and note that aqueous solutions would be ideal for this purpose.

Clue E. Size of waveguide cross-section

If nerve fibres are to serve as optical fibres, then they happen to be about the right size for infrared wavelengths.[41]

Conclusion

Seeing is believing, but how much evidence is needed when seeing is impossible? And what criteria should we apply to such theory-based support?

Looking at scientific method from the broader view of epistemology, one must question whether even the simplest observation can be independent of theory. Indeed the pure objective experiment appears as an unattainable will-o'-the-wisp. It is thus suggested that *overall self consistency* should be the main criterion (encompassing both the theory *and* what we loosely call "observation"). It follows that if we are to make progress when observation is impossible, we may have to fall back on theoretical consistency alone.

Using such an approach, investigators in three separate areas have come to the same general conclusion: that infrared plays an important role in biological communication. This convergence, together with piecemeal experimental evidence, would seem to mutually enhance the persuasive power of all three theories.[33,1,41]

Of these, the theory discussed[41] here concludes that at least some myelinated nerve-fibres can transmit signals in the infrared range, multiplexed with the traditional millisecond pulses and perhaps even serving as carrier for them.

It is further argued that the basic encoders of memory are RNA/DNA-like molecules (rather than synapses or whole neurons). Moreover, it is also suggested that these are not like a tape recording, but rather the survivors of a large-scale selection process: a paradigm which is already accepted for genetics and for immunology. <178>

Taken together with Ashby's notions of hierarchical organization (and Piaget's stages), this appears to offer explanations for a number of mental phenomena.

I am grateful to Dr Charles Osborne for discussing the draft of this paper.

Appendix A: A sketch of the waveguide properties

Field theory approach

Once we accept the possibility of a field-theory/optics interpretation of nerve-fibre geometry and function, there are abundant textbooks on the relevant coaxial waveguide theory. The main problem is that it is not clear what reflection assistance, if any, might exist at the dielectric boundaries. Cope[52] has postulated superconductivity for mitochondrial surfaces; and even if we take a less radical view, it is plausible that there might be (say) an abundance of conjugated double-bonds at such boundaries, thus augmenting conductivity and therefore reflectivity.

Even if there were only a simple two-substance interface, there would still be "total internal reflection": though in our present case we would expect considerable "tunnelling" or "skin thickness" penetration across the boundary and therefore significant attenuation. On another occasion it might be informative to calculate the signal loss in such cases, but that will not be attempted here.[53,54]

Circuit theory approach

This will essentially entail approximations and hence carries the danger of producing misleading conclusions (as mentioned above). Nevertheless, it is instructive to look briefly at this approach, if only because the currently-accepted account lies partway down this path.

The accepted view assumes: (i) that wavelength greatly exceeds transmission distance (which might seem reasonable, but not if we are to consider the whole spectrum including infrared); and (ii) that any inductance effects will be negligible. Given these assumptions, conclusions are drawn from Kelvin's formula for the capacitance of coaxial cable with inner radius a, outer radius b and permittivity ε for its dielectric,[55] rewritten in SI units as:

$$C/\text{length} = 2\pi\varepsilon / [\ln(b/a)] \qquad (1)$$

Then, since capacitive leakage-conductance is given by ωC or $2\pi fC$, the leakage will rapidly kill off any attempt to transmit high-frequency signals.

In fact, this reasoning is only half valid, because the two above-mentioned assumptions eventually break down i.e. when the frequencies become yet higher still, opening the way to "far field" optical effects.

Moreover, if we use the inductive formula analogous to equation (1):

$$L/\text{length} = (\mu/2\pi)[\ln(b/a)] \qquad (2)$$

then that entails a further assumption which begins to break down at this stage: (iii) that the current is uniformly distributed through the two conducting media. In reality though, as the frequency increases, there is an increasing intrusion of the "skin effect".[56] Because a proper treatment of this phenomenon requires us to use the (rival) field theory, it now becomes increasingly questionable whether circuit theory is really an appropriate approach for such phenomena. Why not just accept-the rival formulation in the form of an optical approach (as above)? <179>

References [F]

1. Wei, L.Y. "Electric Dipole Theory of chemical synaptic transmission", *Biophys. J.*, **8**, 396-414 (1968).
2. Lacey, B., *A Dictionary of Philosophy*. Routledge & Kegan Paul, London (1966).
3. Dancy, J., *An Introduction to Contempory Epistemology*, Basil Blackwell, Oxford (1985).
4. Bacon, Sir Francis, *New Organon,* Bobbs-Merrill, Indianapolis [Espec. Sec. xcv] (1620/1960).
5. Piaget, J. and Inhelder, B. *The Child's Conception of Space*. Routledge & Kegan Paul: London (1948/1956/1963).
6. Traill, R.R. and Thomas, L.F., "Practical Theory-Building despite missing data, by applying tests for self-consistency". [Abstract], *Bull. Brit. Psychol. Soc.*, **33**, 25 (1980).
7. Willshaw, D.J., Longuet-Higgins, H.C., and Buneman, O.P. *Nature*, **225**, 178 (1970).
8. Furth, H.G. *Piaget and Knowledge*. Prentice-Hall, Eaglewood Cliffs (1969).
9. Piaget, J. *Traité de logique*. Armand Collin, Paris (1949).
10. Piaget, J. "La logistique axiomatique ou 'pure', la logistique operatoire ou psychologique et les réalités auxelles elles correspondent". *Methodos*, **4**(13), 72-85 (1952).
11. Traill, R.R. *Thinking as mental model-building: a Piagetian-cum-mechanistic explanation of the 'engram'*. Monograph 12, Cybernetics Department, Brunel University (1975). { http://www.ondwelle.com/OSM04.pdf }
12. Traill, R.R. "Acquisition of knowledge without transcendental assistance: an extended Piagetian approach". *Kybernetes*, **5**(2), 73-82 (1976).). {Also as chapters A1 and A2 of Thesis, Ref "30" below}
13. Traill, R.R. "Analytical theory of sensori-motor spatial development". *Kybernetes*, **7**, 61-71 (1978). {Also as chapter A3 of Thesis, Ref "30" below}

[F] The same list is now available *in alphabetical order* in the supplement to this paper (along with some translations of the abstract into other languages): http://www.ondwelle.com/SST88.pdf

14. Hydén, H., "Biochemical Changes Accompanying Learning", in Quarton, G.C. *et al*. (Editors), *The Neurosciences,* p.765 Rockefeller University Press, New York (1967).
15. Blum, M. "Properties of a neuron with many inputs". In von Foerster, H. and Zopf G.W., (Editors), *Principles of Self-organization* [pp 95-120], Pergamon Press: Oxford (1962).
16. Hebb, D.O., *The Organization of Behaviour*. Wiley: New York. (1949/1964).
17. McCulloch, W.S., and Pitts, W.H. "A logical calculus of ideas immanent in nervous activity". *Bull. Math. Biophys.*, **5**, 115-133 (1943).
18. Eccles, J. C., *The Physiology of Synapses*. Springer Verlag, Berlin (1964).
19. Miller, O.L., jr. (1973). "The visualization of genes in action". *Scientific American*, 34-42 and 128 (March 1973).
20. Mednick, S.A., *Learning*. Prentice-Hall, Eaglewood Cliffs (1964).
21. Lashley, K.S., "Studies of cerebral functioning in learning. V. The retention of motor habits after destruction of the so-called motor areas in primates", *Arch. Neurol. Psychiat.,* **12**, 249-276 (1924).
22. Lashley, K.S., *Brain mechanisms and intelligence,* University of Chicago Press (1929).
23. Burnett, F.McF., "A Modification of Jerne's Theory of Antibody Production using the concept of Clonal Selection", *Austr. J. Sci.,* **20**(3), 67-69 (1957).
24. Burnett, F.McF., *The Clonal Selection Theory of acquired immunity,* Cambridge University Press (1959).
25. Pribram, K.H. *Languages of the Brain: Experimental paradoxes and principles in neuropsychology*. Prentice-Hall, Eaglewood Cliffs (1971)
26. Pribram, K.H., Nuwer M., and Baron R.J. "The holographic hypothesis of memory structure in brain function and perception", in Atkinson, R.C., Krantz, S.H., Luce, R.C., and Suppes, P. (Editors.), *Contemporary Developments in Mathematical Psychology*. W.H.Freeman & Co., San Francisco (1974).
27. Ashby, W. R. *Design for a Brain*. Chapman & Hall: London (1952/1960).
28. Beer, S., *The Brain of the Firm*, Allen Lane, London. (1972/1981). — {William Stafford Beer}
29. Beer, S., *Diagnosing the System for Organizations*, Wiley, Chichester. (1985).
30. Traill, R.R. *The Cybernetics of Concepts: an integrated system of postulates to explain their nature…*, Thesis, Brunel University (1978b). (Part C).
{Now online as: *Molecular explanation for intelligence…*,: http://hdl.handle.net/2438/729 (2 files) — or Ondwelle Publications: www.ondwelle.com (7 files); (2006)}.
31. Chapman, L.J. and Chapman, J.P., *Disordered Thought in Schizophrenia*, Appleton-Century-Crofts, New York (1973).
32. Callahan, P.S., "Far infrared emission and detection by night-flying moths", *Nature*., **207**, 1172-1173 (1965).
33. Callahan, P.S., *Tuning in to Nature,* Routledge & Kegan Paul, London (1977).
34. Callahan, P.S., "Picket-fence interferometer on the antenna of the Noctuidae and Pyralidae moths", *Appl. Opt*., **24**, 2217-2220 (1985).
35. Heaviside, O., "On the transmission of energy through wires by the electric current", The Electrician, **14**, p.178- (10 January,1885) — {also in his Electrical Papers, 1, (1892/1970), 434-441 — as "Electromagnetic induction and its propagation: II." }
36. Maxwell, J.C., "A dynamical theory of the electromagnetic field", *Phil. Trans. R. Soc. Lond*., **155**, 459-512 (1865).
37. Rayleigh [Lord], "On the electromagnetic theory of light", *Phil. Mag*., **12**, 81-101 (1865).
38. Moon, P. and Spencer, D.E., *Field Theory for Engineers.*, van Nostrand, Princeton (1961).
39. Katz, B., *Nerve, Muscle, and Synapse*, McGraw-Hill, New York (1966). <180>
40. Thomson, W., [Lord Kelvin], "On the theory of the electric telegraph", *Proc. R. Soc. Lond*., **155**, 382-399 (1855b).
41. Traill, R.R. *Toward a Theoretical Explanation of electro-chemical interaction in memory-use*[*: the postulated role of infra-red components and molecular evolution*]. Monograph 24, Cybernetics Department, Brunel University (1977). {Also as Part B of Thesis, Ref "30" above}.
42. Szent-Györgyi, A. *Bioelectronics*. Academic Press: New York (1968).

43. Alpert, N.L., Keiser, W.E. and Szymanski, H.A., *IR: Theory and Practice of Infrared Spectroscopy*, Plenum Press, New York (1970).
44. Sherebrin, M.H. "Changes in infrared spectrum of nerve during excitation". *Nature New Biol.*, **235**, 122-124 (1972).
45. Fraser, A. and Frey, A.H. "Electromagnetic emission at micron wavelength from active nerves". *Biophys. J.*, **8**, 731-734. (1968).
46. Wei, L.Y. "Role of Surface Dipoles on Axon Membrane", *Science*, **163**, 280-282 (1969).
47. Wei, L.Y. "Dipole theory of heat production and absorption in nerve axon", *Biophys. J.*, **12**, 1159-1170 (1972).
48. Popp, F.A. Becker, G., König, H.l. and Peschka, W. (Editors), *Electromagnetic Bio-Information*, Urban & Schwarzenberg: München (1979).
49. Popp, F.A. Nagl, W., Li, K.H., Scholz, W., Weingärtner, O. and Wolf, R. "Biophoton Emission: New evidence for Coherence and DNA as Source", *Cell Biophys.*, **6**, 33-52 (1984).
50. Konev, S.V., Lyskova, T.I. and Nisenbaum, G.D. "Very weak bioluminescence of cells in the ultraviolet region of the spectrum and its biological role", *Biophys.*, **11**, 410 (1966).
51. Ruth, B. "Experimental investigations on ultraweak photon emission", in Popp, F.A. *et al.* (Editors), *Electromagnetic Bio-Information*, pp.107-121. Urban & Schwarzenberg: München (1979).
52. Cope, F.W. "Electron-phonon (trapped photon) coupling and infrared coaxial transmission line theory of energy transport in mitochondria and nerve". *Bull. Math. Biol.*, **35**, 627-644 (1973).
53. Rayleigh [Lord], "On the reflection and refraction of light by intensely opaque matter", *Phil. Mag.*, **43**, 321-338 (1872).
54. Born, M. and Wolf, E., *Principles of Optics*, Pergamon, Oxford (1970).
55. Thomson, W., [Lord Kelvin], "On the electro-statical capacity of a Leyden phial and of a telegraph wire insulated in the axis of a cylindrical conducting sheath", *Phil. Mag. (Ser.4)*, **9**, 531-535 (1855a).
56. Morton, A.H., *Advanced Electrical Engineering*, Pitman, London (1966).

<181>

{Plus references added via the 2009 annotations and footnotes:}

57. vanWijk, R., (2001). "Bio-photons and Bio-communication", *J. Scientific Exploration*, **15**(2), 183-197. [http://www.scientifiexploration.org/journal/jse_15_2_vanwijk.pdf]
58. Traill. R.R. (2005b). *Thinking by Molecule, Synapse, or both? — From Piaget's Schema, to the Selecting/Editing of ncRNA*. Ondwelle: Melbourne. www.ondwelle.com/OSM02.pdf — Also in *Gen.Sci.J.* www.wbabin.net/physics/traill2.pdf
59. Traill, R.R. (1976/2007). *Short papers and letters on the 'linear micro-element' theory of mental mechanism; and related questions of scientific method*. Ondwelle: Melbourne. www.ondwelle.com/OSM06.pdf
60. Traill, R.R. (1999). *Mind and Micro-Mechanism: a hunt for the missing theory*. Ondwelle: Melbourne. [http://www.ondwelle.com ISBN: 0-9577737-0-6]
61. Traill, R.R. (2000). [Part II of:] *Physics and Philosophy of the Mind*. Ondwelle: Melbourne. [http://www.ondwelle.com ISBN: 0-9577737-1-4]
62. Traill. R.R. (2005c). *How Popperian positivism killed a good-but-poorly-presented theory — Insect Communication by Infrared*. Ondwelle: Melbourne. www.ondwelle.com/OSM03.pdf — Also in *Gen.Sci.J.* www.wbabin.net/physics/traill7
63. Traill. R.R., (2008). *Critique of the 1977 debate on infra-red 'olfaction' in insects — (Diesendorf vs. P.S.Callahan)*. Ondwelle: Melbourne. [http://www.ondwelle.com/OSM09.pdf — Conference of the Australian Entomological Society, at Orange, NSW, Australia: 30 September 2008]
64. Traill, R.R. (2005a). *Strange regularities in the geometry of myelin nerve-insulation — A possible single cause*. Ondwelle: Melbourne. http://www.ondwelle.com/OSM01.pdf
65. Nottebohm, F. (2002) "Why are some neurons replaced in adult brain?" *J.of Neuroscience*, **22**(3), 624-628. http://psych.colorado.edu/~munakata/csh/nottebohm.pdf