the general science journal

The theoretical case that some asbestos fibres could trigger cancer optically, while others act mechanically

Robert R. Traill

email: rrtraill4@dodo·com·au — *Tel.* +61-3-9598-9239
published online by: Ondwelle Publications, 29 Arkaringa Cres., Black Rock 3193, Australia; November 2010
and by the *General Science Journal* — 2010.

ABSTRACT

Asbestos toxicity is non-chemical, implying some "physical" trigger-cause from its geometry — more crystal than reactive molecule. That can include *mechanical interference* with mitosis (sometimes evident for fibres <100nm in width, notably chrysotile, though unlikely at "clumsier" larger size). However the "physical" could also denote *optical effects*, and that accords with the previous paper's ***Postulate 1****: that chemical metabolism is augmented by fast-acting infrared (IR) and ultraviolet (UV) metabolic-signal systems* — repeatedly observed over many decades as "ultra-weak" measurements of escaped bio-photons, and including evidence for UV-involvement in natural mitosis-control. —

Hence ***Postulate 2***: *"That narrow transparent fibres are toxic because they disorganize the supposed UV metabolic-system"* — typically disrupting mitosis via unwanted signal channels. Calculations of the ability of various dielectric fibres to conduct such "short-circuits" at various wavelengths, suggest **(i)** This is possible but only via "zigzag" transmission modes. **(ii)** This can occur *only* for fibres >100nm wide (unless they have a high refractive index: $n > 1.8$, like some *flint glass*). **(iii)** Crocidolite and amosite ("blue and brown asbestos", $n \approx 1.7$) are most capable of carrying coherent laser-like UV when their fibre-widths are in the range 150–200nm (consistent with Stanton/Layard's 1977 claim that the most dangerous fibres were ≤ 250nm in width). **(iv)** Chrysotile ("white asbestos", $n \approx 1.57$) would need to be thicker to transmit UV, and it would be less effective anyhow, especially as its geometry is usually more disordered. That, plus its alternative extra potential for *mechanical* damage may well explain the conflicting claims about its toxicity.

CONTENTS

THE THEORETICAL CASE THAT SOME ASBESTOS FIBRES COULD TRIGGER CANCER OPTICALLY, WHILE OTHERS ACT MECHANICALLY 1

Abstract 1
§1. INTRODUCTION 3
§1.1. Postulate 1: That, in addition to the well-known chemical metabolic system, there also exist IR and UV metabolic systems (regardless of whether or not we yet understand their roles). 3
§1.2. Postulate 2: That narrow optic fibres are toxic because they disorganize the supposed natural UV metabolic-system. 4
§1.3. Points for discussion in what follows 4
Figure 1. Likely causal chains involved in the development of fibre-induced cancer 5
§2. TOWARD A ROAD-MAP OF CAUSALITY AND FEEDBACK 5
§2.2. Primary and Secondary causes 6
§2.3. Postulate 3: That mineral fibres can (at least in part) be bio-recognized as foreign due to their atypical reverberation qualities. 6
§2.4. A Summary of the Fibre-types and their Main Properties 6
Table I. Summary of potentially-toxic fibres and some of their physical properties 7
§3. WHICH WAVELENGTHS ARE COMPATIBLE WITH WHAT FIBRES? 8
§3.1. Preliminaries 8
§3.1.1 Wavelength Bands — a Reminder 8
§3.1.2 Wave-guidance within Rod-like Dielectrics 8
§3.1.3 Strategy for analysing the Quantitative Detail 8
§3.2. Digression to explain "TEM" vs "zigzag" modes 8
§3.2.2 TEM waves. Are they even relevant here? 9
§3.2.3. Anyhow the TEM wavelength still tends to match the diameter, but for a non-zigzag reason 9
Figure 2. The geometry and physics of possible "zigzag" transmission 10
§3.2.4. Non-TEM "zigzag" waves (avoided in most commercial systems) 10
§3.3. So what wavelengths could be travelling through such "toxic" fibres? 11
§3.3.1. Preliminary calculations 11
Table II How zigzag waves within a fibre would depend on their "glancing angle", α 12
§3.3.2. Adjustments for approximate-roundness and refractive index, etc.: 12
§3.3.3. A confusing feedback complication: The deduced λ affects the cause itself!: 13
Table III — successive approximations using Sellmeier's formula to find one stable λ-solution 14
§3.3.4. The somewhat arbitrary "shorter-wavelength limit" (below the sharp upper "cutoff" limit). 14
Table IV Predicted max.wavelengths, when 300nm ≥Diameter≥100nm, and n_{aq}=1.35 15
§3.3.5 Predicting the optical transmission properties of dielectric fibres in general 15
Table V Predicted max.wavelengths, when 300nm ≥Diameter≥100nm, and n_{aq}=1.4 16
§3.3.6 Amosite fibres in particular (and Crocidolite falls within the same range) 17
For n=1.709 (=maximum for amosite) — and with diameters 250/200/150 respectively 17
For n=1.663 (=minimum for amosite) with diameters 250/200/150 again 17
§3.3.7 Likewise for chrysotile (n=1.569) but with Diameters of 300/250/200nm 17
§3.3.8 Comments on these observations 17
§4. CONCLUSION 18
ACKNOWLEDGEMENTS 18
References 19

§1. Introduction

Fibre-toxicity is due to physics rather than chemistry[1]. But the "physical" can take at least two forms, notably "mechanical" (usually assumed), or the *"optical"* which is less obvious and invokes the signalling-or-destructive potential of various wavelengths. These optical bands notably include infrared (IR), the visible, and the more dangerous ultraviolet (UV).

This paper concentrates on these **optical issues** — guided initially by previous apparent-successes which had invoked IR to explain a list of bio-enigmas.[2,3]. In further surveying the literature, it was then surprising to find, not only independent support for the IR-involvement notion, but also persuasive evidence that UV would also have a similar role, though different in detail. (These mutually-corroborative projects are reviewed in Paper 1 of this series[4]).

Metabolic tasks will vary appreciably, with different requirements: Gardeners will often use simple pruning-knives, but sometimes need a *high-energy* chain-saw. Arguably then, metabolism will sometimes require (i) mere benign *IR* to adjust routine ongoing features such as cell-or-myelin geometry; — as against (ii) the need for *UV* to manage *high-energy* changes to more stable settings such as DNA-related configurations.

In any case, we might expect that if UV-based systems are at work, then any malfunction within them is likely to *do more damage (such as carcinogenesis)* compared to IR — just as a dropped chainsaw could have dire consequences, whereas a dropped pruning-knife would probably pass unnoticed.

But while discussing two apparently-new message-systems, it gives perspective to recall that we already accept two. • The first is so obvious that we may tend to overlook it (especially when focussing on *neural* messages) — *viz.* the *endocrine system* — passing **m**olecular "**m**ail" around the body. Accordingly we might now provisionally label this as the "[M]" system.

In contrast there is • the already-labelled[5_{p76-77},6,7_{p2-3}] "[A]" system of **a**xonal ***a**ction-potentials* and their synapses (allowing molecular mail-like messages at each end, but fast electrical code-signals in between) — hence analogous to telegram systems (paper→telegraph→paper). Thus the two "new" methods (if they actually exist) are already part of a tradition of plural signal-methods — and we might plausibly compare them to ♦ *land-line telephones* and ♦*"iPods"*.

At this stage it might help to briefly recall the eight evidence-projects mentioned above, and detailed[4] in Paper 1:

(#A) "Ultraweak" bio-emissions of ultraviolet and infrared photons.
(#B) The brain-theory project — with IR-signals now seen as a necessary adjunct.
(#C) Fibre-optic concepts in telecommunications.
(#D) Cope's trapped-IR-photons in mitochondria.
(#E) Two types of mitochondrial geometry — "oval" (IR?), and now "filament-on-microtubule" (UV?).
(#F) Microtubules as "cell-nerves" radiating from central "brain-and-eye" of cell; — Albrecht-Buehler
(#G) Surprising claims about *benefit* from "Ionizing Radiation" — perhaps fuelling fluorescence of UV.
(#H) Long-range insect navigation, apparently by IR fluorescence from pheromone molecules.

We can now proceed to the two postulates arising from this evidence. Thus:

§1.1. *Postulate 1: That, in addition to the well-known chemical metabolic system, there also exist IR and UV metabolic systems (regardless of whether or not we yet understand their roles).*

This can be restated as claiming that • although important communication certainly occurs using chemical "[M] mail" aided by the well-known "action-potential spikes" of the "**[A]**" system, — *that is only part of the story*. In addition there are apparently two other systems based

more on physics: • "**[R]**", an IR-based system [5$_{p76-77}$,6,7$_{p2-3}$,2] (normally associated with orthodox ATP-like quantum jumps of fairly benign energy levels involving **R**NA-like molecules, and restricted to a range of roughly 20μm[8$_{p57}$] except where it can find an optic pathway through a lipid-or-chitin medium).[6,7] But there is now *also* evidence of • "**[U]**", a UV-system with quantum energies up to about ten-times larger (and wave-geometry ten-times smaller — a matter of some importance when we are concerned with nano-anatomy). This [U]-system seems capable of influencing mitosis, for good *or* ill.

§1.2. Postulate 2: That narrow optic fibres are toxic because they disorganize the supposed natural UV metabolic-system.

This is the main point to be explored in the present paper, so we shall return to it shortly to analyse the technical feasibility of such disruption — here envisaged as unwanted "short-circuit" signal-pathways. Meanwhile it might help to itemize the types of disruption that such short-circuits could cause (on top of any other physical effect the fibres might have, such as *mechanical damage*, discussed later).

Firstly **cross-talk leakage**: If the [U] metabolic system does indeed exist, then it will be sending significant UV messages "intended for Destination X". But if the messages are delivered instead to Destination Y, that could cause as much chaos as accidentally sending a secret government message to a tabloid journalist — or mistakenly sending a box of the Army's hand-grenades to a children's playgroup instead!

Secondly **cross-noise**: Here imagine that Y's own activities are more-or-less corrupted by the irrelevant "noise" from X.

Thirdly there is the possibility of simple **signal-distortion** — where the extra signal-pathways effectively add echo-chambers to the transmission-line, thus smudging the clarity of the signal.

Of these three, the first (cross-talk leakage) seems the most dangerous due to its potential for doing positive damage, whereas the others would probably just impede normal activity. Anyhow these effects seem mutually compatible — so sometimes all three might apply simultaneously.

§1.3. Points for discussion in what follows

Firstly a brief review of current thinking about causal-chains leading to fibre diseases — but emphasizing that this paper is almost exclusively concerned with the "primary causes", whereby the presence of fibres somehow *initiates* the processes. What happens next, the "secondary causes" will mostly involve biochemistry, and will usually have been well discussed in the literature already; so here they will only be mentioned incidentally.

Secondly a quick survey of the main fibres in question, their optical properties, and some opinions about their toxicity.

Then the main task of calculating what wavelengths are likely to be transmitted efficiently by what fibres — bearing in mind their width and refractive index, and their immediate environment with *its* refractive index. This is complicated by the feedback effect whereby refractive indices are themselves dependent on the wavelength in question, especially for UV. However some of the most interesting aspects of the resulting tables are due to this non-linear effect — yielding belated "predictions" consistent with Stanton and Layard's empirical findings on relative toxicity, at least for the amphiboles (crocidolite and amphosite — blue and brown asbestos).

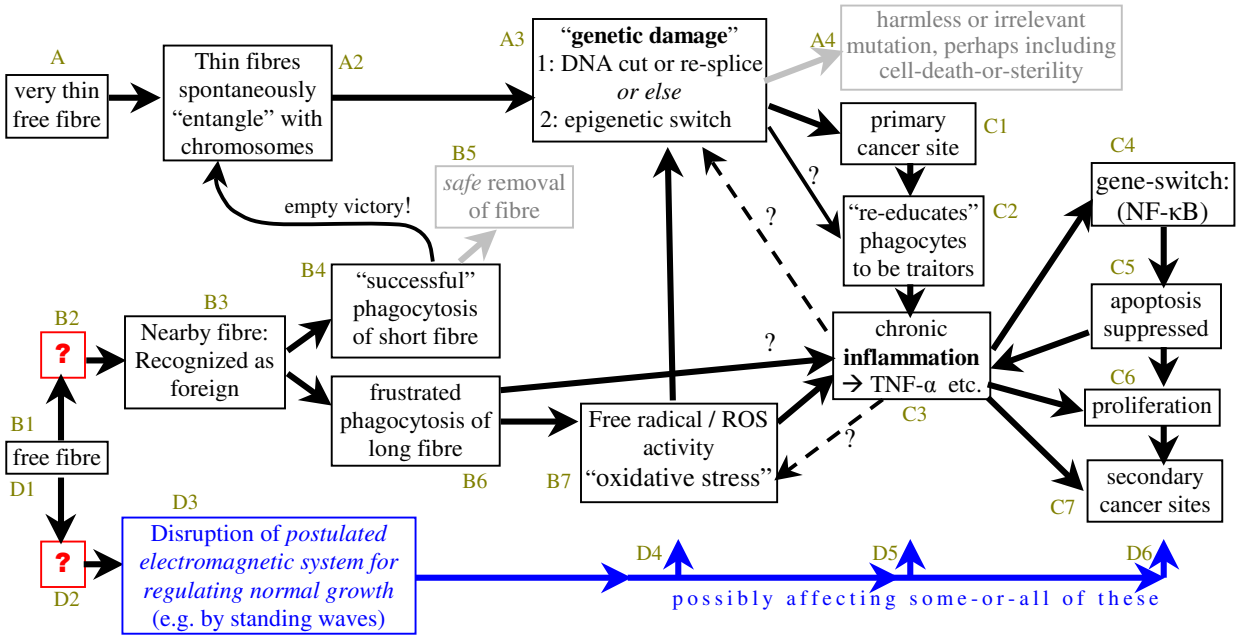


Figure 1. A schematic diagram of various factors thought to be involved in the development and maintenance of fibre-induced cancer — plus some of the causal links which seem likely. *The present paper* is mainly concerned with items in the bottom left of the diagram, notably items **B2** and **D2** (the mysterious non-chemical influences by which fibres of certain dimensions manage to trigger carcinogenesis — the mystery-step which is usually glossed over as if it were unimportant, or somehow "obvious"). The significance of the associated item **D3** will perhaps become apparent during the lengthy §3 below, which calls upon evidence from several other projects involving mysterious non-chemical effects.

The top right of the diagram (**C1-C7**) seeks to summarize the salient points made by Stix (2007)[9], and the rest is based extensively on the reviews by Voytek *et al.*(1990)[10] and by Toyokuni (2009)[11] — but is here intended only to set the context for the latest innovations being considered, and not as an exhaustive account in its own right. Wherever alternative paths are shown, we may provisionally take them all as simultaneously valid until we know better — and, as we might expect, that suggests the existence of feedback in various places.

§2. Toward a Road-Map of Causality and Feedback

§2.1. Figure 1 offers a summary of various correlates of fibre-related cancer development. Of course correlation alone does not enlighten us about causal sequences, but the diagram does also show some current views on what the causalities seem to be. All-or-most of these factors are potentially important, but the ones of chief concern here are the two mysterious "[?]" boxes, bottom left. These implicitly ask: (B2) "How (if at all) can the immune system recognize fibres as being foreign if we rule out chemical cues, and if there is not much in the way of distinctive molecular-scale shapes for antibodies to engage with?" And more importantly: (D2) *"What, if any, is the system which can respond specifically to the actual geometry of the fibres?"* — a question which (when posed that way) points strongly to physics, and indeed to optics.

Other comparable flow-charts are offered by Heintz *et al.*,[12] and by Voytek *et al.*,[10] though they give no clear indication of the ultimate "trigger" causality. That leads us to:

§2.2. *Primary and Secondary causes*

The main concern in this paper will be: "What actually *starts* the carcinogenic process?" That excludes the subsequent symptoms even if they too are causes — *secondary* causes.

The typical trouble is this: Because the real (non-chemical?) primary cause is not measurable in currently-equipped clinics-or-laboratories, one tends to nominate the next secondary cause which *is* observable (or interesting for other reasons). Thus the focus is often on "inflammation" (C3) or the "oxidative stress" (B7) although these are both several steps *down the causal chain* — at least for asbestos diseases.

One does find more helpful accounts which state-or-imply that the body "recognizes" the fibre as foreign (B3), though without suggesting any mechanism (B2). That seems to be only one step down the causal ladder, but still leaving a logical gap given that the usual "lock-and-key" identification-procedure seems improbable for a relatively featureless-and-chemically-inert object like a mineral-or-glass fibre. Thus it makes sense to offer another hypothesis to account for this (comparatively easy?) half (B2) of the general problem:

§2.3. *Postulate 3: That mineral fibres can (at least in part) be bio-recognized as foreign due to their atypical reverberation qualities.*

If true, we can reasonably assume resonant wavelengths which have some relation to each fibre's dimensions. As these would usually differ considerably between fibres, one might expect that what betrays them would be, in part, the unusual *regularity* of this reverberation in each case — as well as its perhaps-unusual range. Alternatively, of course, it could just be the very featurelessness of the fibres which betrays them, given Albrecht-Buehler's accounts of cell-cleverness (Project #F). In either case, we may have some working hypotheses on which to base instructive experimental work – and at least recognize the logical importance of B2.

Most of what follows will be concerned with D2 or its affects on D3.

§2.4. *A Summary of the Fibre-types and their Main Properties*

Already in the 1990s, the *anomalous* opinion-clash outlined in Table I (columns F and G) was a warning that we needed more understanding of the submechanisms. To that end, the preceding paper[4] offered a fresh set of conceptual-tools which we could now use in trying to fill some of the gaps in our comprehension.

Other features which will particularly concern us are: • (column E) the refractive indices; — • (columns C and D) some chemical-and-structural distinctions between Glasses, Chrysotile, and the other "Amphibole" types of asbestos; — and • (columns A and B) the rather confusing number of synonyms which confront us if we cross interdisciplinary boundaries!

And now we need to go into technical calculations. That turns out to be a lengthy task:

Table I•

Summary of the various supposedly-homogeneous dielectric fibres which can be seen as an "asbestos-like" toxic hazard — especially if their diameters are very fine (10–250*nm*). There are two polarized opinions about the relative toxicities of *chrysotile* and the *other (amphibole) asbestos types*, as suggested by the two examples depicted in columns F & G.

	A Names of dielectric fibre-types. w,y,z	B common name	C content-biases, or chemical formulae where: "♣" = $Si_8O_{22}(OH)_2$	D structural pattern	E Refractive Index min – max	F toxic? Merck 1992*	G toxic? Hesterberg† (1987)	soluble?
1	crown "E glass" [v]	(textile)	incl. Ca, Mg, Al, +maybe Na,K,B,F,Ti	amorphous	**1.508– 1.549**	—		?
2	crown glass-wool[v]	(insulatn)	incl. Na, Ca, B, Mg, (+maybe Al, K)	amorphous	**1.530– 1.587**	—		?
3	flint glass [v]	lead glass	incl.Pb, (or Ti, Zr)	amorphous	**… 2.1**	—		**N**
4	(ortho)**chrysotile** = mitaxite	**white asbestos**	$Mg_3Si_2O_5(OH)_4$ [w] (note its uniqueness)	orthorhombic (*serpentine*)[w]	**1.569** – [w] 1.57	slight ?	**6X** query!	**y**
5	Grunerite [w] = **Amosite** = ferro-	**brown asbestos**	$Fe^{2+}{}_7$ –♣ [w]	monoclinic prismatic [w]	**1.663** – [w] 1.709	**XX**	?	**N**
6	(Magnesio)-riebeckite. = (..)-**crocidolite**	**blue asbestos**	$(Na_2Mg_3Fe^{3+}{}_2)$ –♣ $Na_2Fe^{2+}{}_3Fe^{3+}{}_2$ –♣ [y,w]	monoclinic prismatic [w]	[w] **1.68** – 1.70	**XX XX**	**X**	**N**
7	**Tremolite**, (Actinolite) [y] Ferro-actinolite	(rare)	Ca_2Mg_5 –♣ [y,w] $Ca_2(Fe^{2+},Mg)_5$ –♣ [w] $Ca_2Fe^{2+}{}_5$ –♣ [y]	monoclinic prismatic [w]	**1.599** – [w] 1.626	**XX?**	?	**N**
8	Cummingtonite = **Anthophyllite**,	(rare)	Mg_7 –♣ [w, y (*some* Fe)]	orthorhombic [y]	**1.598** – [w] 1.685	slight	?	**N**

[v] Tennent (1971)[13] [w] http://webmineral.com/determin.shtml [14]
[y] Shelley (1985)[15] [z] Mineralogists' usage: Leake (1997) [16]

* TEXT-BOOK ACCOUNT: "Mesothelioma is usually associated with **crocidolite**, one of the 4 main commercial fibers. **Amosite** also causes mesothelioma, but the tumor is very uncommon in those exposed to *chrysotile* and *anthophyllite*. The evidence would suggest that it is not chrysotile that causes the mesothelioma but the presence of **tremolite** as a contaminant of the chrysotile deposits." — (emphases added — *Merck Manual of Diagnosis and Therapy*, 1992. — The 1999 version was similar, but the 2006 edition lacks any such evaluation!). General clinical opinion still seems to agree with the 1992-1999 version, though other views have been expressed — e.g. Hesterberg *et al.* (1987)[17 *abstract*]:

†"chrysotile (LC_{50}, 0.95 µg/cm^2) was about six times more toxic than crocidolite (LC_{50}, 5.8 µg/cm^2)." —— Also note their Fig.2 graphs (page 62).

This clash-of-opinions may be a symptom of the existence of *at least two different mechanisms* which manifest themselves in different circumstances.

§3. Which wavelengths are compatible with what fibres?

§3.1. PRELIMINARIES

§3.1.1 Wavelength Bands — a Reminder

It helps to know what colour is represented by "480*nm*" etc, so I repeat the most relevant part of the previous summary[4]: —— …… *Green* [500nm] ***Blue*** [**450nm**] ***Violet*** [**400nm**] ***UVA*** [**320nm**] ***UVB*** [**280nm**] ***UVC*(*normal*)** [**200nm**] *UVC*(*vacuum*) [10nm=100Å] ……

§3.1.2 Wave-guidance within Rod-like Dielectrics

Project #B had already offered possible logistics for *IR* systems. However *UV*-signals would have rather different needs — notably because water-absorption would not stop the UV from going astray, but also because its wavelengths are shorter and could often be about 1/10 of those for IR (with ten-times the quantum energy). This wave-smallness has implications for any waveguides-or-fibres which might be associated with UV systems, and it will be helpful to look at the reasons in some detail.

As a rough rule-of-thumb, we might expect that any waves within a rod-like wave-guide, will need to be *"short enough for a half-wave to fit 'comfortably' across that rod"* — but not too short, because that requires extra energy and maybe also spoils useful optical effects, *e.g.* laser-like coherence.

In other words: — *Communication-wavelengths* (λ) and *the diameters of their supposed signal-channels* are likely to be of comparable size. Electrical engineers usually *impose* such connections on their systems; — but for biological cases where the system is self-organizing, the causal connection could run either way, (or both ways via feedback).

§3.1.3 Strategy for analysing the Quantitative Detail

Signals can travel along fibres or cables in several different modes (principally "TEM" versus the rest), and these have different properties. Hence to explain the apparent match of wavelength-to-diameter, we need to consider the *TEM* and the *zigzag* (*non-TEM*) waves separately. Thus:

§3.2. DIGRESSION TO EXPLAIN "TEM" VS "ZIGZAG" MODES

§3.2.1. This distinction was a key element in "Project #C" as discussed in the previous paper.[4] Quoting from it concerning the **TEM** mode of wave propagation:

> "Here both the Electric and Magnetic (H) vectors are Transverse, so the energy flows axially: perpendicular to both **H** and **E** vectors — the situation which applies unambiguously when it is travelling unhindered through free space."

This clearcut "straight-ahead" type of transmission will usually be disrupted by boundaries as in a simple fibre. However special arrangements are possible, e.g. in the space *between two conductors* (usually two wires, or a coaxial cable).

Simple transparent rods or fibres can still sometimes transmit radiation efficiently, but only by reflecting back-and-forth across the fibre — taking a **zigzag** course, which means the wavefronts have to travel further, and in the limiting case they simply echo transversely across the rod-or-fibre without progressing axially at all. A further complication is that such zigzag transmissions can only occur in matching pairs so that they criss-cross like this: ><><>< — and when graphed in animated 3D, *the total sum* looks like a series of rounded hills travelling (relatively slowly) down the path.[4,18]

So, returning to the two separate explanations for the apparent match of wavelength-to-diameter:

§3.2.2 TEM waves. Are they even relevant here?

TEM waves avoid the boundary-conditions which dictate the zigzag-geometry of their rivals. They do this either by (i) travelling through empty space; or by (ii) using two conductors (usually wires &/or sheaths, as typically found at the back of TV sets) and travelling through the intervening dielectrics between those two conductors; or (iii) by using rods-or-fibres whose refractive index is slightly greater at the central axis so that the waves can be steered away from the boundaries, — see [4] ("case 4a" within #C — §2.4.5 "Today's Fibre-Optics").

But none of these arrangements seem likely to apply to natural unprocessed *mineral* fibres — nor to ordinary fibre-glass (apart from those specially-made *optic* fibres). However the steered-TEM waves might conceivably occur in *bio-constructed* nature — especially within the postulated UV-metabolic system if it exists Thus it could be instructive to examine carefully the optical properties of those microtubules linked to narrow mitochondria; — etc. Or such conditions might occasionally occur by accident, such as through long-term accretion around a mineral fibre during a latency-period of 20 years or so — though it seems unclear that this could ever be regular enough to be effective, even if it happens in haphazard spasms occasionally.

Discussion of UV on carbon nanotubules (CNT) is mainly deferred to a later paper (in preparation) but bear in mind that *they do* offer some prospect of supporting TEM waves, mainly when clustering increases their effective diameter — and especially as some of the fibres are electrical conductors[19,20] which might form the basis of microscopic coaxial cables if they could acquire a dielectric coating.

§3.2.3. Anyhow the TEM wavelength still tends to match the diameter, but for a non-zigzag reason

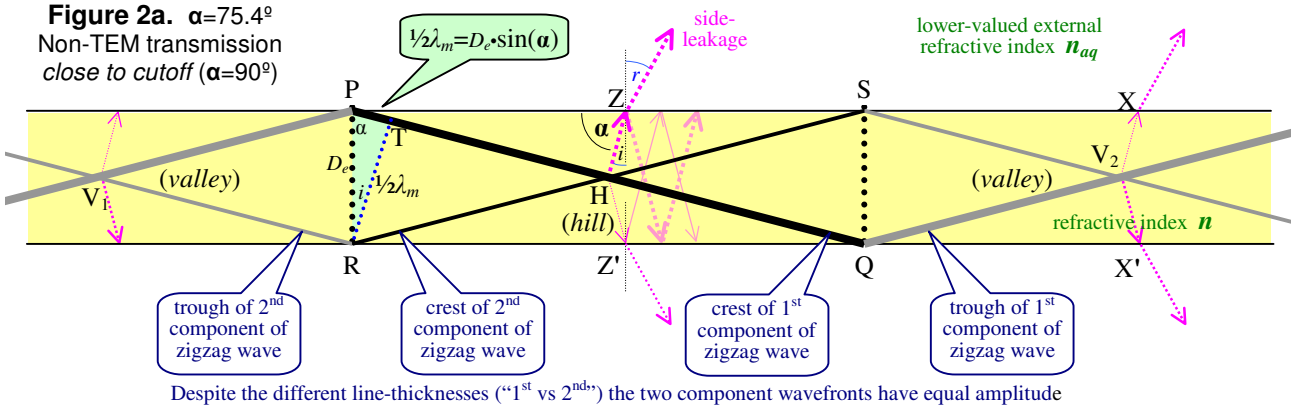
Unlike the zigzag case (discussed immediately below), there is no strict length-cutoff. *In principle* it seems that any wavelength could travel down any TEM-suitable waveguide, nomatter how incongruous the mismatch of sizes. Nevertheless, in engineering practice it is usual to avoid excessively narrow conduits; so is there any rationale for this? It seems that one main problem lies in *how to feed the signal into the conduit efficiently*:

In addition to the technicalities of lenses, aiming, fibre-perfection, and energy-density, there is also the long-recognized phenomenon that waves are increasingly blind to obstacles-or-gadgetry when these shrink through sizes smaller than the wavelength. Lord Rayleigh explained sky-blueness on this basis: (Blue-light is scattered by typical airborne particles, whilst the longer red-light waves tend to ignore the same particles).[21] Thus any "intended entry" aperture (which is effectively an obstacle in reverse) is also likely to be ignored-and-bypassed if it is too small. Moreover the falloff is rather dramatic in certain circumstances, such that:

(*The Aperture's Effective Cross-section*) $\propto (D/\lambda)^4$.(*Actual Area*) — [22$_{p.173}$,23]

where the $(\ldots)^4$ makes the relationship drastically non-linear — and the effect is even more severe if one compares it with the aperture's *radius* rather than its "(*Actual Area*)." Indeed this is the principle which protects users of microwave ovens, despite the *small* holes in the window-grilles.

However, once the signal has actually entered the fibre it may have a comparatively free run. (It could be worth bearing this in mind when considering whether-or-how mitochondria might be feeding signals into microtubules).



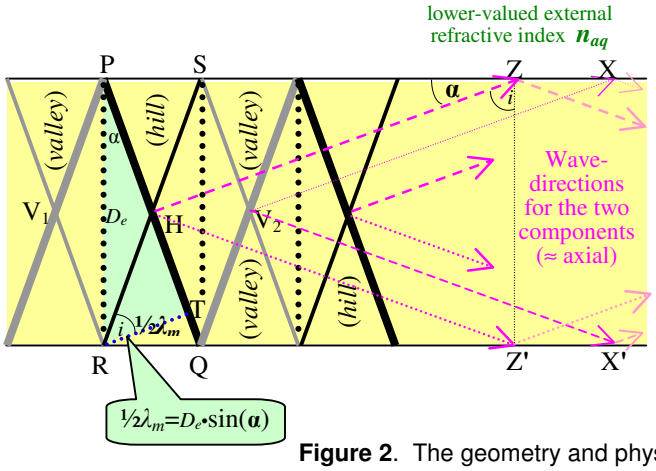


Figure 2b. α=20 º
Non-TEM transmission using TIR (total internal reflection). Here TIR started at α≈37º because $n_{aq}/n = 4/5$

Figure 2. The geometry and physics of possible "zigzag" transmission

§3.2.4. Non-TEM "zigzag" waves (avoided in most commercial systems)

(i) For these secondary-type waves [4#C], first consider the special "cutoff" case where they are simply reverberating transversely across the rod's interior (assuming there is sufficient reflection at the boundary to maintain some semblance of a standing-wave). In "ideal" circumstances (where the "rod" is actually an infinite slab), the lowest-energy standing-wave will indeed be such that *its half-wavelength will exactly match the slab's thickness* IF we ignore refractive index complications. For real systems we need some adjustments:

●a The actual wavelength (**λ_m**) within that medium will be smaller than the nominal *"in vacuo"* wavelength (λ_0), thus: $\lambda_m = \lambda_0/n$ — (where n is the refractive index).
●b For an *actual cylindrical rod of diameter D*, its "effective thickness, ***D*e**" amounts to an *average chord-length* across the fibre: **85.**32**%** of the diameter; so the *whole* wavelength λ_m would be **1.**7064 × the diameter *D*. (The actual mathematical justification for this involves cylindrical "Bessel"-functions instead of sine-waves; e.g. see Skilling's summary[18] of the relevant "$TE_{1,1}$ Mode", (p.217).)

[Three other effects deserve mention, though we may reasonably omit them from the ensuing calculations: ●c Any real-life mirror-effect will involve some slight penetration into the "mirror". This means that the effective reflection-surface is not quite where we expect it to be. ●d Likewise we can ignore the fact that the cross-section will often be only approximately circular. ●e Anisotropy will slightly distort some results.]

(ii) For the wave to start an actual zigzag-travel down the rod, it needs a somewhat *shorter wavelength*. [This arises from the boundary-conditions that the **E**-vector must be zero at the boundaries. That firstly necessitates matching *pairs* of zigzag waves, with criss-crossing wave-fronts thus: XXXXXX, where each black "X" denotes two wave-crests crossing (so there is a "hill" where they intersect), and likewise each grey "X" represents two wave-troughs intersecting (with a bowl-like "valley" where they meet). Thus the perpendicular distances between the "/ / /" lines show us the present λ_m — (and the "//////" lines show the *half-waves* which are more relevant here).

When the wavelength is only mildly shorter than the effective diameter (*e.g.* 75% size), the pattern resembles: XXXXXXX — though *fig.2a* is more extreme, at 97%). Any further shortening produces: XXXXXXXXX and then XXXXXXXXXXXXX (*fig.2b*) — such that the directions of actual wave-travel asymptote towards the ideal axial direction, though at some logistical cost. Also see Skilling[18].

In general, the zigzag wave's travel-angle **α** relative to the axis (the "grazing angle") is given by reorganizing the "$\frac{1}{2}\lambda_m = D_e \cdot \sin(\alpha)$" formula (see the green-or-dark triangles "PRT") to give us:

$$\sin(\alpha) = (\text{RT: } \textit{the actual half-wavelength, } \tfrac{1}{2}\lambda_m) \,/\, (\text{PR: } \textit{effective rod-thickness, } \boldsymbol{D_e})$$

Several very different situations arise according to the value of sin **α**, (i.e. the ratio $\frac{1}{2}\lambda_m/D_e$), and hence also vary with **α** itself. These various situations are depicted in Table II. There we can see that the only significant signal traffic (except over trivial distances) will be when the grazing angle $\alpha \le \alpha_T$ which = $\text{acos}(n_{aq}/n)$ — which is about 37° in a given example with typical figures; (see Table II). [α_T is the angle at which TIR (total internal reflection) begins.]

§3.3. SO WHAT WAVELENGTHS COULD BE TRAVELLING THROUGH SUCH "TOXIC" FIBRES?

§3.3.1. Preliminary calculations

It is convenient to accept Stanton and Layard's categorization[1] of fibre-thickness, *D*:

$$(D=\textit{10nm}) \leftarrow \underline{\text{Most Toxic}} \rightarrow (\textit{250nm}) \leftarrow \underline{\text{Moderately Toxic}} \rightarrow (\textit{1500nm} \equiv 1{\cdot}5\mu m):$$

Even just using the rule-of-thumb (without the various detailed corrections or allowing for individual minerals), we can see that the *"Most Toxic"* range is *likely to coincide approximately* with UVC wavelengths, while the *moderate* range could include:— The milder *UV+Visible+vNIR*.

There is little need for detailed calculations regarding the two extreme figures: The very narrowest fibres (10*nm* diameter), might "in principle" be able to conduct UV of about that wavelength, *but* we have seen that such extreme wavelengths are unlikely to travel viably through matter at all, hence the "UVC(vacuum)" label applied to them earlier. Meanwhile the NIR end of the scale would arguably just fade away into orthodox routine activity. So let us concentrate on the "**250*nm***" (whilst also keeping an eye on *some* of the narrower diameters, perhaps ranging down to whatever the practical limit is — bearing in mind that UV suffers severe absorption in most materials at about 200*nm*, the start of the "UVC(vacuum)" band — a complication we will return to).

Table II: How the zigzag waves (if any) within a homogeneous fibre-or-rod have signal-performances which depend on $½\lambda_m/D_e$, (which = sin(**α**))

#	sin(**α**), (ratio)	**α**, (=90º-*i*) grazing angle	Description	***r***; (angle of refraction)	Can it carry signals?
a	>1	"imaginary"	"cutoff": Won't fit at all	——	NO
b	1	**90º**	Transverse wave only. No axial progression	0º	NO
c	*between*	*between*	*fig.2*: Heavy Leakage	*between*: (0º-90º)	**slightly**†
d	sin… ← e.g. 0.6*	**acos(n_{aq}/n)** = α_T, *eg* 36.87º	Start of **TIR** (Total Internal Reflection) e.g. when n_{aq}/n = 4/5	**90º** [so sin(*r*)=1]	**YES**
e	*between*	*between*	*fig.3*: **Total** Int.**R**eflec.	"imaginary"	**(YES)**
f	0	**0º** (//axis)	Impossible (if zigzag)	"imaginary"	NO

† meagre transmission *unless* there could be a metal-like reflector at the boundary *in lieu* of TIR, (effectively the "case 3" speaking-tubes, see #C, "[…]", within the preceding paper.*) Cope* suggested this sort of possibility, and it just *might* be feasible for his IR systems, but such reflection seems most unlikely here for high frequencies like UV — even if plausible accretions were in place on the fibres.

* By Snell's Refraction Law: $\sin(i)/\sin(r)=n_{aq}/n$ —— Then, at row "*d*": $\sin(r)=1$, so $\sin(i)=n_{aq}/n$ which means that $\cos(\alpha)=n_{aq}/n$

Consider example when n_{aq}=1.3333 and $n=n_m$=1.6667, so n_{aq}/n=4/5=0.8; then $\sin(i)$ = **$\cos(\alpha)$=0.8** means that **α**=36.87º (and of course *i*=53.13º). So the TIR will start (in this case) when $\sin(\alpha)$ descends to 0.60 (=sin 36.87º) i.e. We will have TIR whenever $½\lambda_m \le [0.6] \times D_e$ — provided n_{aq}/n=4/5 — or more generally: whenever $\mathbf{½\lambda_m \le [\sin(\text{acos}(n_{aq}/n))] \times D_e}$ —— **{1}**

And it might help to recall that $[\sin(\text{acos}(x))] = \sqrt{(1 - x^2)}$ — (Pythagoras).

§3.3.2. Adjustments for approximate-roundness and refractive index, etc.:

As we saw on page 10, the *effective* thickness of a round fibre is given by: $D_e = (0{\cdot}8532) \times D$. Also recall that $\lambda_m = \lambda_0/\boldsymbol{n}$ — (by definition for the refractive index ***n***) — and we seek to predict λ_0 for TIR within various fibres having their own individual values for this "***n***". Applying these adjustments to {1} (from the Table II caption), we get:

$$½\lambda_0/n \le [\sin(\text{acos}(n_{aq}/n))] \times (0.8532) \times D$$

so $$\lambda_0 \le \boldsymbol{n}\,[\sin(\text{acos}(n_{aq}/\boldsymbol{n}))] \times (1.7064) \times D \text{ ——} \quad \mathbf{\{2\}}$$

Or, to look further at the particular example considered within Table II (where the "*n*=1·6667" is in the right range for *brown asbestos* (*Amosite*); and the "n_{aq}=1·3333" is plausible for aqueous bio-media. From the Table-caption, we already have $½\lambda_m \le [0{\cdot}6] \times D_e$ —

so this time $½\lambda_0/\boldsymbol{n} \le [0.6] \times D_e$

Thus $\lambda_0 \le (5/3){\cdot}[0.60] \times 2 \times (0.8532) \times (250\text{nm})$. = 426.6*nm* which is in the *violet-light* range, though the "≤" implies some "UV" as well. However there is a problem: —

§3.3.3. A confusing feedback complication: The deduced λ affects the cause itself!:

The above calculation assumes that the two refractive indices (n_{aq} and *n-for-the-chosen-medium*) are both constant. That may be a reasonable assumption for many purposes, but it becomes very misleading at UV frequencies. In fact for most of the supposedly-transparent substances, *n* asymptotes toward some huge value at about λ_0=200*nm* (characteristic of a *peak in absorption* at this point-of-entry to the "UVc/vacuum" band).[24_{p463}]:

Sellmeier's formula [24_{p470}] offers a reasonable approximation to the situation:

$$n^2 = 1 + A / [1 - (\lambda_{absorption}/\lambda_0)^2]$$

where A is a constant for the material concerned, and we can provisionally assume $\lambda_{absorption} = 200nm$ for all relevant media (though in future one might seek more precision). We can then start by solving for A, given that the stated standard "*n*" will actually be n_{Na} — that substance's refractive index for sodium light at the wavelength of 589*nm*, so:

$$A = (n^2 - 1)\cdot[1-(200/589)^2] = [0.8847]\cdot(n_{Na}^2 - 1)$$

so now we have actual "*n*"s as functions of the actual vacuum wavelength λ_0:—

$$n_\lambda = \sqrt{1 + A / [1 - (200/\lambda_0)^2]} = \sqrt{1 + [0.8847]\cdot(n_{Na}^2 - 1) / [1 - (200/\lambda_0)^2]}$$

In our example, equation {2} led us to believe $\lambda_0 = 426.6nm$ — and that now implies:

n_λ (of amosite) $= \sqrt{1+[0.8847]\cdot((\mathbf{5}/3)^2-1)/[1-(200/426.6)^2]} = 1.736629$ and

n_λ (environs) $= \sqrt{1+[0.8847]\cdot((\mathbf{4}/3)^2-1)/[1-(200/426.6)^2]} = 1.3718409$

Calculation notes for the above

$n^2 = 1+[0.8847]\cdot((5/3)^2-1)/[1-(200/426.6)^2] = 1 + [\ \ldots]*(25/9-1)/[1- 0.4688232^2\ ]$
$= 1+ \{\ [0.8847]*1.777777)/(1-0.2197951)\ \}$
$= 1+ \{\ [0.8847]*1.777777)/(0.7802049)\ \}$
$= 1+\ 2.0158805 \qquad =3.0158805$
so (by $\sqrt{}$) n_λ (of amosite) = 1.736629

$n^2 = 1+[0.8847]\cdot((4/3)^2-1)/[1-(200/426.6)^2] = 1 + [\ \ldots]*(16/9-1)/[1- 0.4688232^2\ ]$
$= 1+ \{\ [0.8847]*0.777777)/(1-0.2197951)\ \}$
$= 1+ \{\ [0.8847]*0.777777)/(0.7802049)\ \}$
$= 1+\ 0.8819476 \qquad =1.8819476$
so (by $\sqrt{}$) n_λ (environs) = 1.3718409

But these conclusions seem to contradict our original premise in the caption of Table II, that the two refractive indices would be 1·66666 and 1·33333 respectively (though that assumed a standard wavelength). In fact this is a question of feedback — the putative results *feeding back to influence the original conditions* — and in real life this is common enough (e.g. in economics and electronics). We must simply take the new values as a new starting point and replicate the whole process repeatedly until either: ● the system stabilizes such that the key values *no longer differ* after repeatedly applying the Sellmeier formula, or ● the equations become unsolvable or the successive results increasingly *diverge* — in which case we may *conclude that no stable zigzag transmission of any frequency* is possible in those conditions.

In our present worked-example, successive values for the calculated wavelengths etc. are shown in Table III. (Of course the multi-figure "accuracy" is unrealistic, but it is included to illustrate the mathematical technique). The conclusion is that these fibres should be able to

transmit light with wavelengths of 448nm (violet) and somewhat shorter, perhaps down to 300nm (UVA and some of UVB) before the grazing angle becomes too acute, and before the optical coherence runs into trouble as other vibrational modes become possible. (I.e. from 448*nm* ranging "down a bit" to about 70% of that 448nm for reasons discussed immediately below — though crude theory seems to allow *all* shorter wavelengths).

Table III: Successive approximations in applying the Sellmeier formula to find the stable wavelength for the start of TIR (in the worked example for amosite with a 250nm diameter). A_{aq}=0.68792; $A_{amosite}$=1.573 . Here the degree of "accuracy" is unrealistic and arbitrarily imposed — and of course that marginally influences how many iterations seem to be necessary to reach "constancy" (if any) of the values; but that hardly affects *the overall pattern* which emerges in Table IV.

refr.index amosite: n (prev.λ_0)	refr.index aqueous n_{aq} (prev.λ_0)	n_{aq}/n = $cos(\alpha)$	grazing angle: **α** (degrees)	sin(α)	λ_{med} trial value	**λ_0 trial value**		calcul-ated n^2	calcul-ated n_{aq}^2	Sellmeier's formula gives ← these n^2 & n_{aq}^2 values for the latest **λ_0**-estimate.	#
1.66667	**1.3333**	0.8	36.86993	0.6	255.96	**426.6**	→	3.01614	1.88172		0
1.73670	1.3718	0.7899	37.82735	0.613284	261.6268	**454.36808**	→	2.95101	1.85324		1
1.71785	1.3613	0.7925	37.58359	0.609918	260.1909	**446.96917**	→	2.96679	1.86014		2
1.72244	1.3639	0.7918	37.64368	0.610749	260.5453	**448.77279**	→	2.96285	1.85841		3
1.72129	1.3632	0.7920	37.62873	0.610542	260.4572	**448.32285**	→	2.96382	1.85884		4
1.72158	1.3634	0.7919	37.63244	0.610593	260.4791	**448.43446**	→	2.96358	1.85873		5
1.72151	1.3634	0.7920	37.63152	0.610580	260.4736	**448.40674**	→	2.96364	1.85876	Then one	6
1.72152	1.3634	0.7920	37.63175	0.610584	260.4750	**448.41362**	→	2.96363	1.85875	can use "√"	7
1.72152	1.3634	0.7920	37.63169	0.610583	260.4746	**448.41191**	→	2.96363	1.85875	to get revised	8
1.72152	1.3634	0.7920	37.63170	0.610583	260.4747	**448.41234**	→	2.96363	1.85875	n & n_{aq}	9
1.72152	1.3634	0.7920	37.63170	0.610583	260.4747	**448.41223**	→	2.96363	1.85875	values for the	10
1.72152	1.3634	0.7920	37.63170	0.610583	260.4747	**448.41226**	→	2.96363	1.85875	rext row	11
1.72152	1.3634	0.7920	37.63170	0.610583	260.4747	**448.41225**	→	2.96363	1.85875	(each time).	12
1.72152	1.3634	0.7920	37.63170	0.610583	260.4747	**448.41225**	→	2.96363	1.85875		13

§3.3.4. The somewhat arbitrary *"shorter-wavelength limit" (below the sharp upper "cutoff" limit).*

The wavelength-predictions in Tables III and IV, all nominate the *longest* wavelength which could achieve zigzag transmission efficiently (i.e. with the benefit of TIR), given the stated values for n, n_{aq}, and D. In principle then, any wavelength *shorter* than that could also be transmitted. However there are other factors which we can expect as wavelengths get shorter: (i) The increasing relative fibre-width eventually allows too much freedom for the waves, so that they increasingly lose any laser-like directional effectiveness and other geometric predictabilities. (ii) Wave-shortening allows extra "overtone modes" to invade and contribute their own properties and inconsistent travel speeds etc. — compromising unanimity, or leading to other more destructive interference. (iii) The glancing angles, (already about 37º, see Table IV), would become increasingly more-acute, making the reflection more vulnerable. (iv) Shorter waves are more vulnerable to small irregularities anyhow, as Rayleigh showed (see above).

Perhaps one cannot put an exact theoretical figure on it, but it is probably reasonable to assume an effective shorter-wave limit of about 70% of the long-wave cutoff shown in the tables. (The main influence here is consideration of "(ii)" since extra modes start becoming evident at about that level — and by the stage of 50% one even has octaves to deal with). Anyhow that gives us some guidance on the actual range of frequencies expected to be effective in such domains: —— *The stated wavelength and down to about 70% of it* — this being the *"shorter-wavelength limit"*. (It would be somewhat misleading to call it a "minimum").

vNIR

Table IV: Predicted max.transmitted wavelength for fibres of diameter "D" — when n_{aq} (sodium light) = **1.35**

Fibre-Diameters: →				D=**300***nm*		D=**250***nm*		D=**200***nm*		D=**150***nm*		D=**100***nm*	
Wavelength in vacuo (λ *nm*) *and* angle α° at start of TIR: →			refract^ve index	λ	glance-angle α°	λ	glance-angle α°	λ	glance-angle α°	λ	glance-angle α°	λ	glance-angle α°
"n"data source=[14]		Max?	***n***	≤…	≤…	≤…	≤…	≤…	≤…	≤…	≤…	≤…	≤…
xanthoconite			***3***	**1305.40**	62.61	**1093.44**	62.68	**882.94**	62.81	**675.29**	63.06	**474.23**	63.71
pinalite (*n*=2.49, 2.95)		approx	***2.5***	**1032.71**	56.70	**867.67**	56.82	**704.43**	57.04	**544.63**	57.47	**392.50**	58.53
diamond			***2.417***	**985.84**	55.45	**828.94**	55.58	**673.92**	55.82	**522.47**	56.30	**378.87**	57.45
flint glass		max	***2.1***	**799.94**	49.54	**675.72**	49.75	**553.74**	50.13	**435.86**	50.85	**326.58**	52.45
alumotantite			***2***	**738.14**	47.18	**624.97**	47.43	**514.17**	47.87	**407.69**	48.70	**309.99**	50.47
klebelsberqite			***1.95***	**706.44**	45.88	**598.99**	46.15	**493.99**	46.62	**393.40**	47.52	**301.67**	49.39
Lammerite			***1.9***	**674.11**	44.48	**572.53**	44.78	**473.49**	45.29	**378.95**	46.25	**293.34**	48.22
parwelite			***1.85***	**641.06**	42.98	**545.53**	43.31	**452.62**	43.86	**364.33**	44.89	**285±1**	46.95±
rouseite			***1.8***	**607.16**	41.35	**517.90**	41.71	**431.35**	42.32	**349.51**	43.42	*fails*	
warikahnite			***1.75***	**572.27**	39.58	**489.54**	39.98	**409.60**	40.64	**334.47**	41.82	*fails*	
amosite	brown	max	***1.709***	**542.78**	38.00	**465.63**	38.43	**391.36**	39.14	**321.95**	40.40	*fails*	
crocidolite	blue	max	***1.7***	**536.19**	37.63	**460.30**	38.07	**387.30**	38.80	**319.18**	40.07	*fails*	
anthophyllite	(rare)	max	***1.685***	**525.09**	37.01	**451.33**	37.47	**380.48**	38.21	**314.53**	39.50	*fails*	
crocidolite	blue	min	***1.68***	**521.37**	36.80	**448.32**	37.26	**378.20**	38.01	**312.98**	39.31	*fails*	
amosite	brown	min	***1.663***	**508.57**	36.07	**437.99**	36.54	**370.37**	37.32	**307.67**	38.64	*fails*	
attakolite		min	***1.65***	**498.66**	35.48	**430.00**	35.97	**364.33**	36.77	**303.59**	38.12	*fails*	
tremolite	(rare)	max	***1.626***	**480.03**	34.36	**405.02**	34.88	**353.04**	35.71	**295.99**	37.09	*fails*	
tremolite	(rare)	min+	***1.6***	**459.33**	33.08	**398.42**	33.62	**340.58**	34.49	**287.66±**	35.91	*fails*	
anthophyllite	(rare)	min	***1.598***	**457.72**	32.97	**397.13**	33.52	**339.61**	34.39	**287.0±**	35.8	*fails*	
E-CrownGlass	(textile)	max	***1.5874***	**449.08**	32.42	**390.22**	32.98	**334.45**	33.86	**286±22**	35±1	*fails*	
chrysotile	white		***1.569***	**433.83**	31.42	**378.05**	32.01	**325.38**	32.91	*fails*		*fails*	
armenite (*n*=…-1.552)		min	***1.55***	**417.70**	30.34	**365.22**	30.94	**315.86**	31.88	*fails*		*fails*	
otherCrownG.	wool-glass	max	***1.5487***	**416.58**	30.26	**364.33**	30.87	**315.20**	31.80	*fails*		*fails*	
E-CrownGlass	(textile)	min	***1.5302***	**400.41**	29.13	**351.52**	29.76	**305.75**	30.73	*fails*		*fails*	
otherCrownG.	wool-glass	min	***1.5076***	**380.02**	27.66	**335.42**	28.32	**293.95**	29.30	*fails*		*fails*	
bilinite			***1.5***	**372.98**	27.13	**329.89**	25.84	**289.92**	28.80	*fails*		*fails*	
gearksutile			***1.45***	**323.91**	23.22	**291.69**	23.93	*fails*		*fails*		*fails*	
natron			***1.405***	*fails*		*fails*		*fails*		*fails*		*fails*	
qilianshanite		min	***1.351***	*fails*		*fails*		*fails*		*fails*		*fails*	
ferruccite			***1.301***	*fails*		*fails*		*fails*		*fails*		*fails*	

UVA

UVB

§3.3.5 Predicting the optical transmission properties of dielectric fibres in general

We can now apply the above technique to fibres of various diameters and refractive indices. Following Thar & Kühl [25], Table IV guesses that the external aqueous refractive index (n_{aq}) = 1.35 (instead of 1.3333 in the above example). Then, as a test of the significance of the n_{aq} value, the calculations are repeated in "Table V", using n_{aq} = 1.4 instead.

In fact the most interesting feature of these two tables is the enforced *absence* of figures in the bottom right-hand regions. If the argument and calculations are correct, this means broadly that ● all such fibres may be able to transmit certain electromagnetic signals efficiently in *some* circumstances; and yet ● the narrowest fibres will be quite incapable of transmitting *any* such signals efficiently, whatever the wavelength.

In particular, no fibres with n<1.8 and D≤100nm will be capable of such zigzag transmission without debilitating loss.

Table V: Predicted maximum wavelength for fibres of diameter "D" — when n_{aq} (sodium light) = **1.4**

Fibre-Diameters: →				D=**300***nm*		D=**250***nm*		D=**200***nm*		D=**150***nm*		D=**100***nm*	
Wavelength in vacuo (λ *nm*) *and* angle α° at start of TIR: →			refract^ve index	λ	glance-angle α°	λ	glance-angle α°	λ	glance-angle α°	λ	glance-angle α°	λ	glance-angle α°
		Max?	***n***	≤…	≤…	≤…	≤…	≤…	≤…	≤…	≤…	≤…	≤…
xanthoconite			3	**1293.14**	61.57	**1083.27**	61.64	**874.88**	61.76	**669.37**	62.01	**470.48**	62.63
pinalite (*n*=2.49, 2.95)		approx	2.5	**1017.16**	55.37	**854.82**	55.49	**694.30**	55.70	**537.27**	56.12	**387.96**	57.14
diamond			2.417	**969.54**	54.05	**815.48**	54.18	**663.33**	54.41	**514.78**	54.88	**374.17**	55.99
flint glass		max	2.1	**779.76**	47.79	**659.14**	48.00	**540.79**	48.37	**426.62**	49.07	**321.11**	50.61
alumotantite			2	**716.22**	45.27	**607.00**	45.52	**500.21**	45.95	**397.80**	46.76	**304.22**	48.46
klebelsberqite			1.95	**683.50**	43.87	**580.22**	44.14	**479.43**	44.61	**383.14**	45.48	**295.74**	47.26
Lammerite			1.9	**650.04**	42.37	**552.86**	42.67	**458.28**	43.17	**368.29**	44.10	**287.23±**	45.97
parwelite			1.85	**615.69**	40.74	**524.85**	41.07	**436.69**	41.62	**353.23**	42.61	*fails*	(45±5)
rouseite			1.8	**580.31**	38.97	**496.07**	39.33	**414.60**	39.93	**337.92**	41.00	*fails*	
warikahnite			1.75	**543.70**	37.03	**466.38**	37.43	**391.92**	38.08	**322.34**	39.22	*fails*	
amosite	brown	max	1.709	**512.57**	35.29	**441.22**	35.72	**372.82**	36.42	**309.33**	37.62	*fails*	
crocidolite	blue	max	1.7	**505.59**	34.88	**435.58**	35.32	**368.55**	36.03	**306.44**	37.25	*fails*	
anthophyllite	(rare)	max	1.685	**493.81**	34.19	**426.10**	34.65	**361.38**	35.37	**301.60**	36.61	*fails*	
crocidolite	blue	min	1.68	**489.84**	33.96	**422.91**	34.41	**358.98**	35.15	**299.98**	36.39	*fails*	
amosite	brown	min	1.663	**476.20**	33.13	**411.95**	33.61	**350.73**	34.36	**294.44**	35.62	*fails*	
attakolite		min	1.65	**465.60**	32.48	**403.44**	32.97	**344.34**	33.74	**290.16**	35.02	*fails*	
tremolite	(rare)	max	1.626	**445.59**	31.21	**387.44**	31.73	**332.37**	32.53	*div.oscil*	35±5	*fails*	
tremolite	(rare)	min+	1.6	**423.21**	29.74	**369.60**	30.28	**319.10**	31.12	*fails*		*fails*	
anthophyllite	(rare)	min	1.598	**421.46**	29.62	**368.20**	30.17	**318.07**	31.01	*fails*		*fails*	
E-CrownGlass	(textile)	max	1.5874	**412.06**	28.99	**360.74**	29.54	**312.55**	30.39	*fails*		*fails*	
chrysotile	white		1.569	**395.39**	27.83	**347.54**	28.40	**302.82**	29.27	*fails*		*fails*	
armenite (*n*=…-1.552)		min	1.55	**377.61**	26.54	**333.53**	27.14	**292.57**	28.02	*fails*		*fails*	
otherCrownG.	wool-glass	max	1.5487	**376.37**	26.45	**332.56**	27.05	**291.86**	27.93	*fails*		*fails*	
otherCrownG.	wool-glass	min	1.5076	**335.46**	23.29	**300.62**	23.92	*fails*		*fails*		*fails*	
E-CrownGlass	(textile)	min	1.5302	**358.40**	25.10	**318.47**	25.72	*div.oscil*	27±5	*fails*		*fails*	
bilinite			1.5	**327.47**	22.63	**294.43**	23.27	*fails*		*fails*		*fails*	
gearksutile			1.45	*fails*		*fails*		*fails*		*fails*		*fails*	
natron			1.405	*fails*		*fails*		*fails*		*fails*		*fails*	
qilianshanite		min	1.351	*fails*		*fails*		*fails*		*fails*		*fails*	
ferruccite			1.301	*fails*		*fails*		*fails*		*fails*		*fails*	

vNIR

UVA

UVB

(For this Table V the λ figures are each roughly 12-to-40*nm* less than in Table IV, and its α values are about 2º-4º less, but it is otherwise quite similar).

§3.3.6 Amosite fibres in particular (and Crocidolite falls within the same range)

Looking at the actual figures in Table IV for the shaded amphibole asbestos-types (for which n=1.663–1.709), the maximum-wavelengths for ***D*=250nm** range from **465.63 (blue)** to **438.99 (violet)**, and the corresponding 70% *"shorter limits"* are *326 (UVA) – 307 (UVB)*. Or we can continue rather more systematically (whilst highlighting those particular figures):

For n=1.709 (=maximum for amosite) — and with diameters 250/200/150 respectively

If n_{aq}=**1.35**: λ_{max}=**465.63(blue)–/**391.36(UVA)–**/**321.95(UVA)
& 70% λ_{short}= *326(UVA)*—**/**–274(**UVC**)—-**/**—225(**UVC**)

If n_{aq}=**1.4**: λ_{max}=441.22(violet)**/**372.82(UVA)–**/**309.33(UVB)
& 70% λ_{short}= 309(UVB)—**/**–261(**UVC**)—**/**217(UVC, *near 200 limit*)

For n=1.663 (=minimum for amosite) with diameters 250/200/150 again

If n_{aq}=**1.35**: : λ_{max}=**437.99(violet)/**370.37(UVA)**/**307.67 (UVB)
& 70% λ_{short}= *307 (UVB)*—**/**–259 (**UVC**)–**/**–215 (**UVC**).

If n_{aq}=**1.4**: λ_{max}=411.95(violet) **/**350.73(UVA)**/**–294.44(UVB)
& 70% λ_{short}= .288(UVB)—**/**—246(UVC)–**/**–206 (UVC, ***very*** *near 200 limit*)

§3.3.7 Likewise for chrysotile (n=1.569) but with Diameters of 300/250/200nm

If n_{aq}=**1.35**: λ_{max}=433.83(violet)**/**378.05**/**325.38(UVA) and λ_{short}=304(UVB)**/**265**/**228(UVC).
If n_{aq}=**1.4** : λ_{max}=395.39**/**347.54(UVA)**/**302.82(UVB) and λ_{short}=277**/**243**/**212 (all UVC).
But no transmission for chrysotile fibres thinner than about 175nm.

§3.3.8 Comments on these observations

(1) Stanton and Layard[1] claimed that the most dangerous diameter-range is 250nm-10nm. The calculations here tend to support that claim theoretically by suggesting that (for amphiboles) the 250nm–150nm fibres seem best suited to conducting various types of UV — waves which are likely to do damage if directed inappropriately and maybe we should include violet also). For chrysotile the corresponding range is about 300nm–200nm.

(2) That does not account for Stanton's remaining *D*iameter values down to 10nm. But recall that those very thin fibres offer the *alternative* risk of *mechanical* damage; (see "A2" within Figure 1). Such a *duality of mechanisms* could possibly explain anomalies or apparent contradictions; — (further discussion in preparation, concerning the chrysotile controversy). Also note the similar comment by Ault *et al* (1995[26]: p792): *"The ability of asbestos to cause a variety of different diseases … indicates that asbestos must have multiple mechanisms of action."*]

(3) "Wool-glass" (n≈1.52) could well be similar to chrysotile, other things being equal; but if its fibres are usually significantly thicker than 300nm, it could be relatively benign.

(4) It could be interesting to experiment with fibres of high refractive index, such as various grades of flint-glass — though it might be difficult to obtain satisfactory *fibres* of such materials.

§4. Conclusion

What exactly is it about asbestos-like fibres that triggers carcinogenesis, and just how does that happen? If we acknowledge that the initial effect is not chemical (even though subsequent events may be), then we need to look for "physical" causes. That could manifest as **mechanical damage**, and this paper has supported that view — at least for cases involving very narrow fibres (<100*nm*, and especially <60*nm*), where the sizes of chromosome and fibre are close enough for them to readily entangle if circumstances actually bring them together. (Also see sequel, in preparation).

But other causes can act independently, and this study has been more concerned with the simultaneous risk of **optical causes**, given that any prism of dielectric offers scope for optical phenomena.

The most interesting optical effects arise from *optical interference*, such as when the prevailing wavelengths are comparable to the size of the relevant medium. It just so happens that the most dangerous fibres are said to have widths of <250*nm* — and if we exclude the mechanical-risk cases, that leaves us with a range of about 250*nm*–150*nm*, comparable to the usual wavelengths for ultraviolet light (UV).

Meanwhile, as was reviewed in the previous paper, there is strong case for considering the surprising possibility of important hidden metabolic signalling via UV emissions from a second type of mitochondrion.

Following that hypothesis, a second hypothesis here suggests that any optic-toxicity of asbestos fibres comes from the risk that they will supply inappropriate "short-circuit" conduits between UV-dependent centres — thus upsetting natural activities, *especially mitosis*. There is also the lesser risk that they will simply distort the natural signal traffic.

Acknowledgements

I am grateful to Professor William Bains (Cambridge) and to Dr Glen Reid of ADRI (Sydney University), Concord NSW, for useful correspondence on related topics.

REFERENCES

1 Stanton,M.F., and Layard,M. (1978). *The carcinogenicity of fibrous minerals*. National Bureau of Standards Special Publication 506 — from Gaitherburg conference of July 1977.

2 Traill,R.R. (2008a/2005b). *Thinking by Molecule, Synapse, or both? — From Piaget's Schema, to the Selecting/Editing of ncRNA*. Ondwelle: Melbourne. www.ondwelle.com/OSM02.pdf [French version: www.ondwelle.com/FrSM02.pdf].

3 Traill,R.R. (2009). *Real Mechanisms for Natural Thought? The History of an in-depth Analysis*. Ondwelle: Melbourne. www.ondwelle.com/OSM12.pdf

4 TraillR.R. (2010 Oct). *Meaningful UV and IR photon-exchange within bio-tissue? — Interdisciplinary evidence, and a new way to view asbestos toxicity*. Ondwelle: Melbourne. www.ondwelle.com/UV1_evidence.pdf — and also General Science Journal on the present website.

5 Traill,R.R. (1999). *Mind and Micro-Mechanism: a hunt for the missing theory*. Ondwelle: Melbourne. http://www.ondwelle.com

6 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

7 Traill,R.R. (1976b/2007). *The gulf between behavioural psychology and fundamental physiology: a systematic attempt to bridge the gap*. Monograph 15, Institute of Cybernetics, Brunel University. (Paper presented at the workshop on Memory during the annual conference of the British Psychological Society, York, April 1976).(www.ondwelle.com/OSM05.pdf)

8 Traill,R.R. (2000). *Physics and Philosophy of the Mind*. Ondwelle: Melbourne. http://www.ondwelle.com

9 Stix,G. (2007 July) "A Malignant". *Sci.Amer.*, 297(1), 42-49 .

10 Voytek, P., M.Anver, T.Thorslund, J.Conley and E.Anderson (1990). "Mechanisms of Asbestos Carcinogenicity". *J.Amer.College of Toxicology*. **9**(5), 541-550.

11 Toyokuni,S. (2009) "Mechanisms of asbestos-induced carcinogenesis" [review]. *Nagoya J. Med. Sci.*, **71**, 1-10.

12 Heintz,N.H., Janssen-Heininger,Y.M.W., and Mossman,B.T. (2010). "Asbestos, lung cancers, and mesotheliomas: From molecular approaches to targeting tumor survival pathways". *Am.J.Respir.Cell Mol.Biol.*, **42**, 133-139.

13 Tennent,R.M. (ed.)(1971) *Science Data Book*. Oliver & Boyd: Edinburgh.

14 Webmineral.com (2010 June 21: main access): http://webmineral.com/determin.shtml ; http://webmineral.com/determin/biaxial_minerals.shtml ; http://webmineral.com/determin/isotropic_minerals.shtml

15 Shelley,D. (1985). *Optical Mineralogy*. Elsevier: New York

16 Leake,B.E. (chairman) *et al.* (1997). "Nomenclature of amphiboles: …". *The Canadian Mineralogist*, **35**, 219-246. [Their preferred system, which differs from medical usage].

17 Hesterberg,T.W., Ririe,D.G., Barrett,J.C., and Nettesheim,P. (1987). "Mechanisms of cytotoxicity of asbestos fibres in rat tracheal epithelial cells in culture". *Toxic. in Vitro*, **1**(2), 59-65.

18 Skilling,H.H. (1948). Chap.13: *Fundamentals of Electric Waves*. Wiley. — [especially pp.198-217].

19 Dresselhaus,M.S., Dresselhaus,G., and Saito,R. (1995) "Physics of Carbon Nanotubes". *Carbon*, **33**(7), 883-891.

20 Kataura, H., Kumazawa,Y., Maniwa,Y., Umezu,I., Suzuki,S., Ohtsuka,Y., and Achiba,Y. (1999) "Optical Properties of Single-Wall Carbon Nanotubes". *Synthetic Metals*, **103**, 2555-2558.

21 Rayleigh [Lord] (1899). "On the transmission of light through an atmosphere containing small particles in suspension, and on the origin of the blue of the sky". *Philosophical Magazine, (Series 5),* **47**, 375-.

22 Bethe,H.A. (1944). "Theory of diffraction by small holes". *Physical Review*, **66**(7), 163-182.

23 Weiner,J. (2009) "The physics of light transmission through subwavelength apertures and aperture arrays", *Rep. Prog Phys.*, **72**, 064401 (19pp). [http://iopscience.iop.org/1063-7869/51/10/R01]

24 Jenkins,F.A. and White,H.E. (1950). *Fundamentals of Optics*. McGraw-Hill: New York & London.

25 Thar,R., and Kühl,M. (2004). "Propagation of electromagetic radiation in mitochondria?". *J. Theoretical Biology,* **230**(2), 261-270. http://www.mbl.ku.dk/MKuhl/pages/PDF/Thar&Kuhl2004.pdf

26 Ault,J.G., Cole,R.W., Jensen,C.G., Jensen,L.C.W., Bachert,L.A., and Rieder,C.L. (1995) "Behavior of crocidolite asbestos during mitosis in living vertebrate lung epithelial cells" *Cancer Research.* **55**, 792-798.

