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Remarks on Culture and the Self

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Introduction

The objective in this essay is to look at the basic mechanism involved in the formation of the mind within the total context in which human beings assume their general ecological niche. Because the brain of man develops largely *ex utero,* and therefore primarily in a social context, the formation of the mind is naturally dominated, and indeed governed, by the remarkable process of the acquisition of language.

This process has two major aspects: the transfer of culture from the community to each of its members, and the resulting formation of the self. These two sides of acculturation provide the rationale for the division of this essay into two main substantive sections, one an examination of the notion of cultural transfer, the other an analysis of the notion of the self and of its correlates. These are preceded by a few general remarks on particular aspects of language which are relevant to the topic under discussion.

A study of this sort may be approached from a variety of angles. In the present case, the approach is essentially Wittgensteinian, in that the notion of deep grammar (i.e. the grammar of meaning) plays a central role in showing how conceptual attitudes are affected by cultural transfer, both in the case of the acquisition of language, and in the more general case of the transfer of information from one cultural area, such as science, to some other such as art, religion, policy, etc.

A—On Language

The importance of language to philosophical inquiry derives from the fact that all of our knowledge about the world and about our selves is given form and expression in language. Thus all of our claims to know or to believe are claims about what we say so that the analysis of what we say is the analysis of what we mean. Malebranche put it rather well when he said that "language is the locus of thought, as space is the locus of body". Language viewed in this light is the principal carrier of intelligence, for it is by its means that we make ourselves understood.

I—Remarks on Language

How we understand ourselves and our world is determined in large part by the tools we use to do it. The principal ones, language and the conceptual framework embedded in it are both inherited. In the case of man, where most of the brain develops *ex utero,* the cultural "wiring" takes place in a social environment. It is marked in particular by the acquisition of language.

Language is formative of the mind: it gives it a preferential attitude, as well as a point of reference from which to observe nature and learn from it. In this sense no two languages can translate accurately into each other: for in addition to the fact that the brain's "wiring" differs in each case, a particular sensitivity and a way of perceiving are assumed with the acquisition of a new language. Furthermore, the perspective inherent in any view of nature does not itself admit of translation but requires something akin to a conversion, a sort of "Gestält shift" in order to be got right. It is the sense in which the limits of my language are truly the limits of my world, the sense in which language embodies a form of life. For language is symbolic, and a symbolism presupposes a whole conceptual stage setting, as well as an extrinsic context in which symbols have their point.

In some cases, a specialised and more perspicuous language can be constructed effectively whenever it is thought that the structure of the natural language lacks the kind of precision that perspicuity of representation alone makes possible. For example classical musicians have developed a written symbolism that represents with sufficient precision the structure of the musical phrase; in similar fashion mathematical physicists have devised several languages having the multiplicity required for the analytical representation of natural phenomena by means of their structural properties. Indeed the present century has been marked *inter alia* by the development of many such specialised languages, even in areas where the need was not originally recognized. The point of these remarks is that, hidden by the grammatical structure of the natural language lies the deeper grammar of the conceptual framework. In principle, this deep grammar (the grammar of meaning) can be made overt by using a suitable symbolism.

II—Remarks on Concepts

A key notion of the theory of description is that of *concept*: it functions as the primary referring expression. Concepts play a dual role in description: a referential role whereby an expression is linked with elements of a domain of interpretation (e.g. when we ask, of an object, what it is); and a grammatical (formal) role, it being the manner in which such an expression is related to others in the language (as when we ask of a term what it means). These two aspects are intimately linked, the former being dependent on the latter.

The *grammatical aspect* of a concept is given by the way in which the term used to represent it relates to other expressions in the language. This aspect is a direct consequence of the partial interpretation of an underlying network of relations, the "syntactical mesh". The interpreted mesh defines the *conceptual framework* within which reference can be made to some elements of the domain of interpretation. In principle, it is always possible to formalize the conceptual mesh, though this is seldom useful outside of the theoretical disciplines, such as mechanics. The formal character of a concept is thus nothing other than the grammatical aspect of its meaning, i.e. its *deep grammar*. While the deep grammar of an expression is seldom evident from its apparent structure the situation can be remedied (as pointed out earlier), and the deep grammar made overt in descriptive contexts by the use of a notation designed specifically for that purpose, should the need for one be found.

The *referential aspect* of a concept typically underdetermines its formal aspects, so that it is not rare for the latter to undergo evolutionary developments as the cultural framework changes while its reference is left materially unchanged. A given term, while referring to a particular entity, may impute to it vastly different properties, depending on which conceptual framework it is enmeshed in. For example, what is meant by "atom" differs considerably to day from what was meant by it a hundred years ago, even though its denotation has not changed markedly since then.

The referent of a concept is given in terms of some general property represented by a predicate function. Individual instances of the concept are singled out through the circumstances attendant to the actual use of the predicate function, there being no reason, philosophical or otherwise why there should be a single instantiation rather than many, or none.

Therefore to say of something that it is an object of a particular kind is to embed it in a conceptual framework; in this sense, it is appropriate to say that the world we know, that is the one we describe, is conceptually laden [1]. Therein are to be found the philosophical roots of conventionalism.

A referring expression, considered by itself, does not reveal its meaning in use, and may in fact be associated with different conceptual frameworks on different occasions, a condition typical of natural languages. In such cases, the use of the same expression to refer to different entities helps to hide the differences in meaning, an effect compounded whenever the referent picked out is the same object in each case. Ambiguities such as these are inevitable in ordinary discourse where a number of cultural attitudes come together.

III—The Argument Against Private Language

The argument against the possibility of there being a so-called "private language" [2], presented by Wittgenstein in the "Philosophical Investigations", includes two main points that are made in criticism of the view that language can be private in a nontrivial, philosophically interesting way.

The first point has to do with the widespread assumption, more or less explicitely endorsed by philosophical writers since antiquity, that the meaning of descriptive expressions is in some essential way dependent on their referents, rather than the other way around (referential theories of meaning).

Wittgenstein argues that, even in the paradigmatic case of names, referential theories fail to account for the meaning of referring expressions primarily, though not exclusively, because the existence of their referents is immaterial to their sense whether these be construed in the classical manner as public objects (such as Julius Ceasar or the circle) or as private objects in the manner of the Moderns (i.e. as states of consciousness) [3].

The second point has to do with the observation that it is not possible to use language in unheard-of ways in order to effect a publicly defined task, such as referring, describing, promising, and so forth.

The upshot of this is an argument for the inescapably public character of all meaningful expressions, including those reporting on states of consciousness, whether to oneself or to others.

B—On Culture

This part is divided into two sets of remarks. The first group is designed to highlight various aspects of human culture, with language as its principal distinguishing feature. A number of important notions are introduced here; these in turn set the stage for a discussion of the phenomenon of cultural transfer.

The second set of remarks is given to various aspects of cultural transfer. The frequent emergence of cultural gradients within societies undergoing this process reveals the existence of stresses associated with information transfers across cultural boundaries; it also points to the importance of having a *lingua franca* to cut across ideological lines and to help in the emergence of new syncretic cultures within societies marked by a measure of cultural heterogeneity (including world society).

I—Remarks on Culture

The culture of a people results from the activities they engage in. The more varied these activities, the richer the culture is likely to be.

Human activities are modes of adaptation to the world which man inherits at birth. Some of these are clearly intended to improve personal survival (e.g. farming), while others affect the survival of the social group as a whole (e.g. organizing). Others are designed to improve the quality of life (e.g. medicine), or one's understanding of nature (e.g. the natural sciences). Some activities are meant to achieve a significant mode of expression for one's aspirations (e.g. the fine arts), while still others probe beyond the limits of nature and reach for the transcendent (e.g. religion).

To talk of the culture of a people is not to say that all of the individuals in society engage in all of the activities constitutive of that culture. For aside from the obvious case of the elderly and the young whose scope of activities is limited, people tend to specialize, a process which adds to the survival value of society and to the quality of its culture. The division of labors leads inevitably to an uneven distribution of cultural activities and, by way of consequence, to an uneven distribution of the benefits such activities bestow. So we may ask, what does it mean to talk about the culture of a people if it is the culture of no one in particular?

In general, human societies are culturally identifiable in terms both of a common language and of social institutions (government, laws, etc). These provide the stage upon which the development of culture and the differentiation of its elements can take place.

Of the cultural traits that give cohesion to human society, language is by far the most significant. The natural language first acquired by an infant (the mother's tongue, so aptly called), enmeshes it into the common social and cultural fabric by giving it the means to understand itself and its world. Eventually the language will enable the child to objectify its own self and thereby to become a person in the accepted cultural sense of the word.

Each of the constitutive elements of a culture (i.e. each of its constitutive activities) has its own conceptual framework, and to that degree its own language. The businessman and the politician, the artist and the physicist, the farmer and the lawyer, each lives in a different cultural world, a fact normally hidden by the shared natural language. In this sense we may look upon the activities imbricated in the general culture as its *subcultures*.

Different as they may be, these subcultures are obviously connected and influence each other. The over-all pattern they form, and the relative importance of each component within the whole, define the *cultural profile* of a society, and thereby provide it with a criterion of cultural identity. This in turn makes possible the comparison of different cultures. In general the more complex the cultural fabric, the richer it is, the wider is its scope and the greater are the possibilities of its growth.

A cultural profile may evolve with time. Changes in the cultural profile tend to occur gradually. Sometimes however, abrupt changes take place, which mark the onset of cultural revolutions. The scientific revolution, the French revolution, the industrial revolution, the technological revolution, among others, are instances of this phenomenon.

In general, the rate of change in the culture of a society tends to be uneven, and this introduces a degree of cultural stratification. The most influential factor in this process of cultural change is undoubtedly the finite but appreciable time it takes for new information to be acquired, processed and distributed, those at the leading edge, where the information originates being different from most of those who make use of it. Once received, the new information is usually processed further and re-emerges eventually in a degraded but more useful form (i.e. one that is less general).

II—On Cultural Transfers

The net effect that the acquisition of new information has on the recipient is a modification of his conceptual framework, which in turn affects his whole cultural attitude. Therefore, it is to be expected that the transfer of information will create a *cultural gradient* between its source and its users. The time of diffusion is almost always substantial, and by the time the new information has been absorbed and used by those most distant from its source, the leading group is likely to have evolved conceptually beyond the stage at which the information originated, further steepening the gradient. As a result those at the leading edge of change do not share the same conceptual attitude with those at the trailing edge, a situation familiar to students of the sociology of science.

Ordinarily, the cultural gradient is steeper across professional lines than it is within the sub-culture itself: people engaged in different pursuits find it harder to communicate about what interests them than those who are engaged in the same enterprise and share the same conceptual apparatus (e.g developments in the biology of mind filter more rapidly through the group working in the cognitive sciences than it does across professional lines and take even longer to reach the general public).

If the cultural gradient becomes too steep (a situation often encountered at times of rapid developments, especially across professional lines), discontinuities are likely to appear in the general cultural fabric. Depending on their nature and importance, these in turn may elicit strong reactions within society, perhaps reinforced by the perceived incompatibility of assumed facts with values held (Cf e.g fundamentalism, environmental extremism, and so forth).

On the global scale, such discontinuities are likely to generate enmity, and perhaps even open hostility to the activities of the society with the most advanced culture (Cf. for example, the attempts by Third World countries to control both the acquisition and the flow of information through UNESCO).

As the specialized language of each subculture differentiates out of the common matrix, the associated conceptual frameworks begin to evolve in different ways and eventually become incommensurable i.e the point is reached when there is no longer any way to translate from one language into another with any precision. The best that can be hoped for in a situation like this is to paraphrase the original text in the natural language shared by all (for example, it is not possible to translate from the language of plasma physics into English, and to then proceed with the physics in that language, any more than it is possible to translate the poetry of Dylan Thomas into French, and expect to achieve the same poetic effect in that language as in English. Nor is it possible to translate Beethoven's Triple Concerto in any natural language).

Yet in general it is possible to paraphrase into a richer if less perspicuous language and to invoke canons of correctness suitable to the process, thereby transferring *some* information across cultural lines. Even though the paraphrase is not a true translation since the information is being distorted in the process, a transfer does takes place which is sufficient to affect the cultural framework inherent in the richer language.

In this manner, the general cultural framework can be modified by the transfer of some information across the lines that divide its various sub-cultures. What is required then is a suitable medium, a *lingua franca* sufficiently plastic and rich to encode changing notions having their origins in specialised languages with esoteric conceptual grammars. The result will be a modified cultural framework, and therefore a different way of seeing things. In this way general cultures evolve.

C—On the Self

A special case of cultural transfer is that of the acculturation of infants, where the effect of transferring the language is marked by the initial formation of a self and by its subsequent development into a person.

What follows should not to be read as the articulation of a particular view regarding the notion of the self, but simply as indicative of the sort of points such a view would include. Still the proposed schema should be sufficiently clear to give a reasonably fair idea of the theory here suggested.

The underlying assumption in what follows is that a non-speaking organism has no concept of self. This is meant to exclude animals as well as some higher organisms deprived of the cultural environment needed to acquire linguistic competence at birth (for example "l'Enfant Sauvage" of Aveyron, the wild boy Ramu of India etc). This should not to be construed to mean that a higher organism with the capacity for self-consciousness cannot have a perception of self. The only claim made here is that such an organism does not have *a concept of self*. This notion can evolve only through the process of adaptation of a suitably complex organism to its integral environment. This last includes, in the case of human organisms being discussed here, the cultural and especially the linguistic dimension. For if we do not take into account the degree of anatomical complexity needed for self consciousness and for its verbal expression, nor the obvious cultural dimension of the environment in which man makes his niche, the only way sense can be made of the performance of a human organism is to treat it as a "black box" i.e. as a purely mechanical system designed to transform certain inputs into corresponding outputs. The drawback of this approach is that black boxes have no selves!

That the approach proposed here is not the only way to approach the self is evident, but it has the merit of presenting a model that is human in the cultural sense of the term. Man is admittedly a very complex and sophisticated organism, but it is not just that: it has emergent properties, chief among which is thinking. In this sense Man is, first and foremost, *homo linguificans*.

I—The Notion of the Self

The notion of *the self* that emerges from these considerations is roughly as follows:

Selves are not born, they are made. The self, although it may be genetically predetermined in important ways, is formed mostly in the context of its cultural environment. The key to this process is the acquisition of language, the importance of which can hardly be underestimated. It is the crucial event which provides the infant with the means to express itself verbally, and to map its world. This however is a slow process, mostly because the brain of the infant is not all there at the time of birth. What may be called figuratively "the wiring of the brain for language" cannot proceed before the Central Nervous System (or Central Information System: CIS) has developed sufficiently. Therefore the actual wiring takes place in an environment in which language is normally used. It is in this manner that the infant learns how to speak whatever language or languages are spoken in its immediate cultural niche.

Once acquired, this verbal mode of expression enables the infant to objectify itself, i.e. to perceive itself as an object, as a person in the culturally defined sense of this term. (Cf in this context the interesting though seldom noted contrast between the criteria used by Descartes to define his own self, which are introspective, and those, purely linguistic, which he used to ascertain that there are other selves [4]).

II—The Self in Context

The self, having inherited its formal properties through the language used to map its features, may be expected to bear the imprint of its linguistic matrix.

To the extent that the context in which an infant is immersed is not culturally homogeneous, its emerging self will be complex and reflect in its structure the variety of conceptual frameworks associated with each component of the culture. Such a complexity is apparent for instance in the multiplicity of culturally inherited traits, ranging from the the diversity of the kind of archetypes studied by C. G. Jung, to other social traits of character (national, tribal, family, etc).

The complexity of the self is also the result of the multitude of conceptual frameworks at work in any given human culture, however unsophisticated. It is common for these frameworks to overlap in much of the domain of ordinary experience. Added to the fact that a person understands himself only in terms of some conceptual framework, this circumstance leads naturally to the emergence of a multitude of co-referential selves, each bearing the imprint of a set of formal characteristics derived from a different grammatical (conceptual) matrix. This unique cluster of selves will be referred to as *the Self*, with a capital S.

In this manner the formation of the individual Self is often marked, perhaps inevitably, by profound inconsistencies. Whenever the circumstances are right, these inconsistencies can manifest themselves and create perceptible tensions within the individual, from which pathologies may in due course develop.

We may infer from this what the main task of therapy could be: to first identify the *locus delictus*, and then to undertake whatever remedial action is appropriate. Presumably, this would result in the smoothing out of the kinks in the conceptual fabric.

III—The Self as Person

A *person* may be defined as a physical organism functioning as the referent of multiple selves. Its principal feature is its Central Information System (CIS): it enables the organism to generate, to process and to diffuse information, as well as provides it with a serviceable ground for identity.

Being a physical organism, a person normally interacts with similar organisms, as well as with the over-all material environment. Its mode of interaction with the environment is naturally physical, that is mediated through the body, but it is also non physical in important respects, especially as it relates to similar organisms, with whom the most important interactions are mediated by language, the essential carrier of intelligence.

The person-to-person interactions, and to a lesser extent perhaps the person-to-world interactions, are formative of the person and may be expected to contribute to its complexity. Taken together, these interactions entwine the individual in a complex network of relations which forms the stage within which the person lives its history. Such complex enmeshments make for numerous interactions, leading to the appearance of endogenous forces in the Self. From their interplay, there emerges a fine structure which is uniquely characteristic of that individual.

IV—Egogeny, Identity and Privacy

Three points remain to be mentioned in order to present a reasonable overview of the notion of the Self.

Defined and understood in terms of language the Self is naturally of a public nature. Yet it is eminently private in an important sense. The reasons for this are to be found in the natural unity and uniqueness of the person itself. Three key elements are constitutive of this privacy, namely the integrity of the person as a single organism, the historical development of the Self, and the priviledged mode of access the person has to its own Self.

The *internal integrity* of the person is derived from the principle of its organization: the existence of its Central Information System. The CIS provides one important criterion of identity, by being relatively invariant through the vicissitudes of the life of the organism. While the person adapts to the changing environment, and the Self develops and complexifies, its growing sense of internal integrity gives form to the increasing awareness of its own identity. In this way, it provides the person with the grounds for the co-referentiality of its different constitutive selves. The lived experience of this internal integrity may be said to constitute the material basis for the *privacy* of the Self and of the person.

The Self is complex, a direct consequence of the very complexity of the ambient culture. It is an ensemble of interactive selves, all referred to the same organism or person. It is also a unique succession of time-indexed worlds in which the same person plays the central role. This succession of worlds, as well as their defining characteristics, combine to create a *unique history*: that of the formation of the Self (*egogeny*).

Given that each person has a *priviledged* and *immediate access* to its own consciousness, and therefore an incorrigible knowledge of its contents, the unique configuration of its formal features may be said to be private, notwithstanding the fact that each of its constitutive elements is essentially public in character: it is private to the extent only that it is actualised in a single person, and thus directly accessible by that person alone.

It is important to keep in mind that the Self so defined is not a thing (i.e. a substance), and therefore is not to be construed as a referent. The Self, as defined here, is the *form* of consciousness, itself the emergent property of certain organisms whose CIS is of a particular nature and degree of complexity. Its referent is the person, the ultimate ground of identity.

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The Influence of Natural Resonances on Scattering and Radiation Processes

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ABSTRACT

Resonances present in the many physical processes associated with radiation and scattering phenomena are being used in many applications ranging from radar target masking to sonar target identification.

Introduction

Resonances have traditionally been regarded as an engineering problem. Many an engineer has lived in fear of designing a structure destined to go into an environment where the ambient spectrum contained a large amplitude at one of the structure's resonances. Two famous tragedies which justify the concern are: the collapse of Tacoma Narrows Bridge and the loss while in flight of some Lockheed Electras, an early turboprop airplane. This has led to a historical revulsion to the concept of resonance and probably leaves many engineers feeling that nothing good could ever come from such a troublesome phenomenon. Not so!

Here, instead, we emphasize that the spectrum of resonances inherent in a physical structure carries information about the structure's size, shape, and material composition. Looked at this way, this phenomenon takes on the appearance of a relatively unacknowledged reservoir of information.

Singularities are the spice of life! Without them, many physical phenomena would not exist. "Analytic functions without singularities must be constants," states a well-known theorem of analysis,[1] and eternally constant behavior is hardly an interesting state of affairs. Here, we are concerned with resonances, which are singularities (or, mathematically, division by zero) that serve to define the physical characteristics.

Many physical processes of a wave-nature contribute character to their sources through their resonant content. For instance, when we hear a familiar voice we recognize the unique juxtaposition of resonant qualities which serve to identify the individual. We naturally store the experience of hearing a person's voice for later use in identification. The same sort of recognition occurs using optical phenomena where color provides a resonant activity which serves to help distinguish the source.

In scattering theory, singularities in the scattering amplitudes of the waves returned by objects are caused by their natural resonances. Each object has resonances that are unique and which are communicated, like a fingerprint, to its echo. Once one deciphers the code about shape and material composition that the scatterer's resonances impart to its echos, it becomes possible to use them for characterization purposes.

Resonances in physical processes have a peculiar commonality and uniformity. A recently developed theoretical tool, the resonance scattering theory,[2] (RST), seems to possess a degree of universality which makes it ideal for use as a general investigative tool for the many physical wave processes which exhibit resonance. The details of the methodology have been discussed in many technical[2,3,4] and non-technical[5] articles, but its essence may be reviewed as follows. Whenever an incident wave falls upon an object, the object is invited to vibrate with all the frequencies present in the incident wave. The object will, however, naturally respond by vibrating only with that peculiar subset of frequencies which is also present in its resonance spectrum. The RST consists of a series of steps that ultimately isolate the body's resonances as they appear buried within the active echo that the body returns. The echo can be viewed as a characteristic signature, in frequency or in time, of the object that generated it. Thus, RST is a potential target identification tool. The first step of RST models the scatterer as *penetrable*, with interior fields coupled to outer fields through boundary conditions at the object's surface. The second step requires an analysis of each one of the modes or partial waves that form the object's summed cross section. The third step separates the two basic contributions contained within each mode. These are in the form of smooth continous backgrounds and discrete spiky resonances. The backgrounds depend on the scatterer's shape, but assume it to be impenetrable. The resonances are effects of the penetrable composition of the body, and they manifest themselves as discrete dips/peaks superimposed on the smooth backgrounds. They correspond to the penetration of energy into the object which only occurs through discrete spectral windows centered at the object's resonances. For bodies with non-separable shapes, the decomposition of the cross-section into modal or partial wave portions is not possible, and the contribution from the backgrounds and the resonances are separated from each other in the complete or summed cross-section instead of in each of its partial waves.

It is essential to understand the difference that consideration of a body as penetrable versus impenetrable makes. First, one must remember that the Rayleigh region is where the wavelength is large compared with the size of the target object, and, hence, where the scattering process is predominantly due to the phenomenon of diffraction. At the other extreme of the spectrum, the geometrical region, the wavelength is much smaller than the object's size and here the scattering process

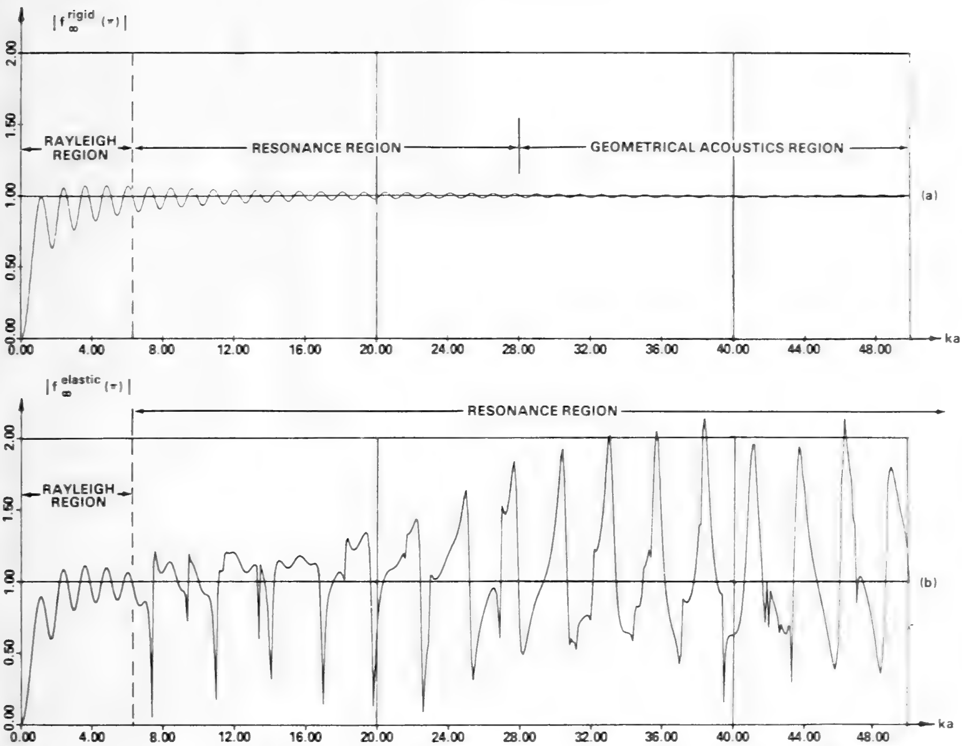


Fig. 1 (a) Form function of an impenetrable (rigid) sphere of radius "a" in water is shown as a function of ka ($=2\pi a/\lambda = \omega a/c$). Various scattering regions are shown on this spectral plot. (b) Form function of an elastic (tungsten carbide) sphere in water. The resonance region widens.

is, for the most part, a result of refraction and reflection. For an impenetrable body, the resonance region separates the Rayleigh region from the geometrical regime. (See Figure 1a.) For a penetrable body, this is not the case. The resonance region, above the Rayleigh region, propagates out into the geometrical regime (see Figure 1b). The resonance region is therefore considerably enlarged. The importance of the Resonance Scattering Theory for penetrable objects stems from recognition of this fact.

Resonances appear everywhere in physical processes which involve wave phenomena. Typical examples are in areas such as acoustics (sonar), ultrasonics/elastodynamics, mechanics of solids, electromagnetism (radar), geophysics, optics, and nuclear physics. Complex resonance phenomena present in some of these areas have been theoretically explained in the past. In other instances, the explanation is still lacking. In all instances, there has been little attempt at unifying the treatment of resonances in all of the above fields with a universal approach.

In what follows, we will illustrate the various areas with examples from each one. This will form a collection of examples of quite dissimilar physical processes, that could all eventually be explained by this new methodology. In Section I we shall point out the few cases in which the methodology and the explanation are already available; and in Section II we call attention to the current ongoing application of this method to new situations.

I. Acoustic, Solid State, and Electromagnetic Resonances—A Common Bond

Let's begin the development of our collection with three examples from the disciplines of underwater and physical acoustics. When a sound wave emerging from a distant source is incident on a submerged cylindrical shell, the resulting backscattering cross section is as shown in Figure 2a, taken from Ref. 6, with resonance features clearly evident. In this early study (1965) of small cylindrical shells, the various types of resonances observed in the backscattering cross sections at various frequencies were categorized according to their partial wave origin, an RST-type idea. It was not until later, however, that a full RST analysis of a similar problem,[7a] a study of an air filled cylindrical aluminum shell in water, was performed. A result from this study is shown in Figure 2b, and what was previously good guess work has now become clear. The resonances which are only dependent upon the cylinder's composition have been isolated here from the geometry or shape dependent background. From plots such as these we can reexamine the cross section diagram and identify every one of its features (Fig. 2c). Many theoretical predictions of RST have been confirmed experimentally.[7b]

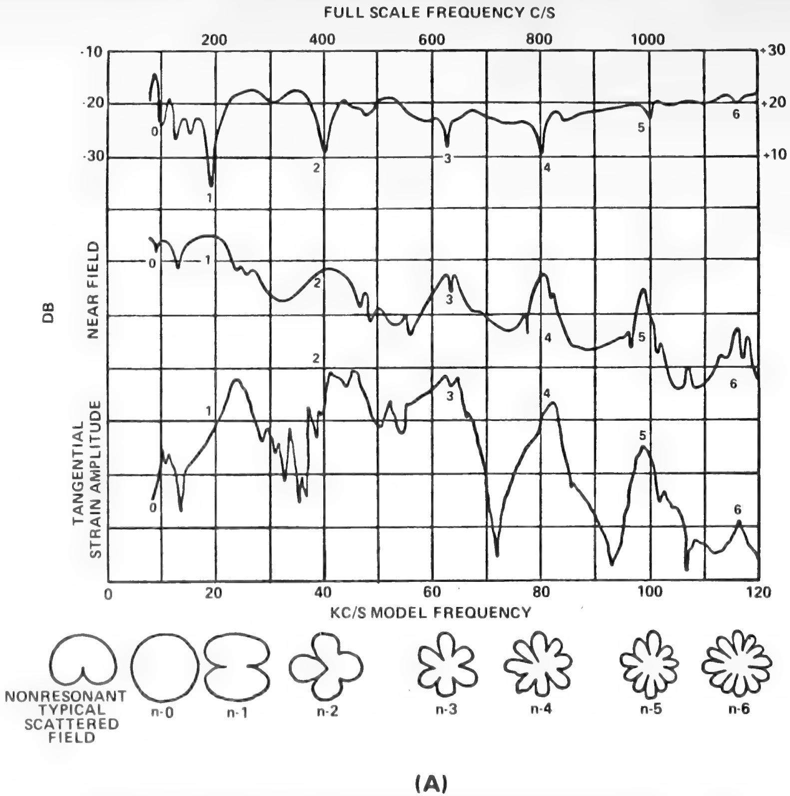
An even earlier (1951) but similar study,[8] also foucused on acoustic resonances. Here the bistatic (i.e., receiver and source at different locations) scattering cross section of a solid elastic cylinder in water is shown versus the angle θ between the incident and scattered beams for three different values of frequency. It was observed that when the frequency of the incident sound wave matches one of the resonant frequencies of the object, a significant decrease occurs in the backscattered signal ($\theta = 180°$).

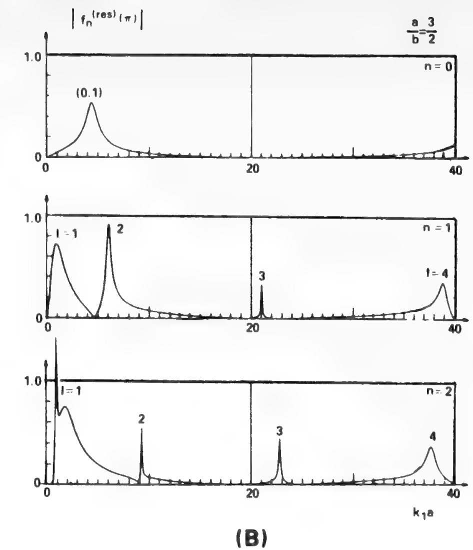
Yet another RST analysis[9] in 1979 has furnished a clear picture of what is actually happening in this problem. The null is caused by absoption of energy at a frequency which corresponds to a natural resonance of the object. These resonance frequency values are given by the roots of characteristic equations which occur as a result of applying the RST. If we choose one of these resonances which cause a quasi-null and plot the form function or scattered wave amplitude versus angle θ we should expect to see a null in the backscattering direction, $\theta = 180°$, and we do. Also, the near null at $\theta = 180°$ seen in Figure 3, will quickly be filled in and disappear when it is redone for any frequency value slightly away from the resonance value (even 1% away).

Further study of acoustic resonances appear in the analysis of a different type of problem: that of wave propagation through bubbly liquids. When a sound wave travels through a cloud of gas bubbles in water, the wave exhibits an effective sound speed and effective attenuation much larger than if the bubbles were not present. This phenomenon has been measured[10] and then predicted by RST[11a] with good agreement between the two. It is shown that this behavior is completely controlled by the acoustic resonances of the individual bubbles, which taken together produce a cumulative effect. Analogous studies have been carried out for viscoelastic solids containing perforations.[11b]

We continue the list with two examples of ultrasonic resonances in solids.

A fluid filled cavity within a solid can be excited by an incident elastic wave. Of particular interest to those who work with underwater sound absorbers is the case of a spherical, air filled cavity in a rubber matrix. Such a cavity was set into oscillation by an incident compressional wave, and the cavity's pressure amplitude was plotted versus frequency in Ref. (12). The simple theory presented in Ref. (12) to describe a vibration problem was later generalized within the context of scattering, and in particular, of resonance scattering,[13] with the following results. The cavity exhibits a big resonant peak which is caused by its monopole mode of oscil-





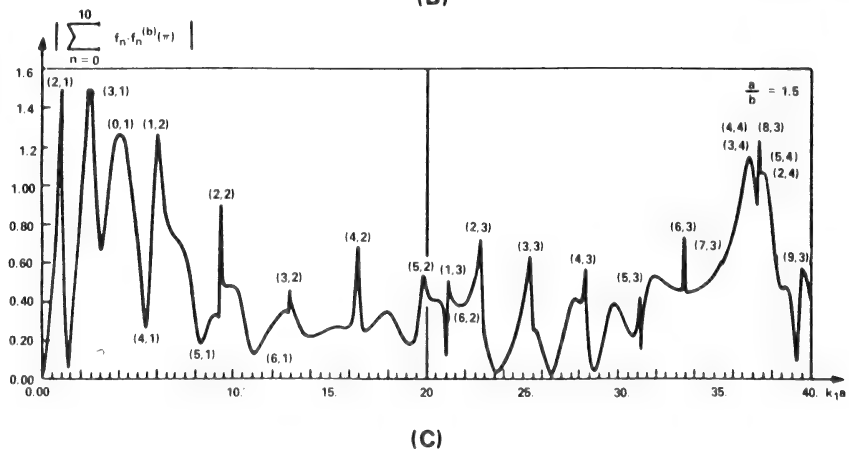
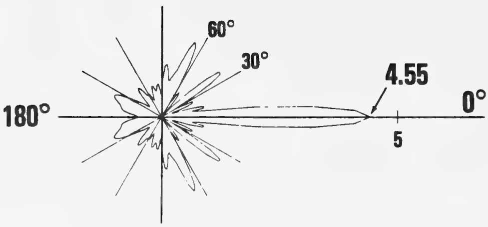


Fig. 2 (a) Form function (whose square is the backscattering cross section) for the cylindrical portion of a model submarine at normal incidence. The model is a 1% scale model of the prototype. Several types of acoustic resonances are identified. (From Ref. 6). (b) The first few (n = 0,1,2..) isolated modal resonances of an aluminum tube, obtained by suitable (rigid) background subtraction, and displayed versus k_1a. The index *l* labels each one of the resonances which occur for each partial wave n. (From Ref. 7a). (c) Form function for the aluminum tube with all the modal rigid backgrounds suppressed. This figure accounts for many sets, (n,*l*), of modal resonances such as the three shown in Figure 2(b). (From Ref. 7a).



(5,2) RESONANCE, ka = 19.5429

Fig. 3 Bistatic form function versus θ at a single selected resonance frequency (viz, x_{52} = 19.5429). A Faran type[8] of minimum or dip at θ = 180° is clearly observed. This dip disappears for values of $x = k_1a$ slightly away from the value of the (5,2) resonance at 19.5429. (From Ref. 9).

lation (n = 0), and which is quite similar to that seen in bubbles[11] and in nuclear physics.[14] For a single cavity, the spectral location of the peak changes with the cavity contents and size, and with the matrix composition.

Metal matrix composites have also been investigated for resonant behavior. A water filled cylindrical cavity contained within an aluminum matrix, has been excited by an incident elastic compressional pulse. Its backscattered spectrum is plotted versus frequency in Figure 4, which is taken from Ref. (15). Oscillations in this cross-sectional plot are due to the resonances of the fluid in the cavity.

It should be noted that the literature in this area is mostly concerned with measurements and, thus far, the inherent spectrum of resonances has only been analyzed for the purpose of sizing the cylinder's diameter. In fact, a variety of (largely experimental) studies of different types of elastic waves scattered by inclusions within elastic media, such as those in Refs. (12), (15), and (16), have been completed in recent years, and still await general theoretical treatments which focus on the observed resonant behaviors.

Our next two examples come from a seemingly very different area of physics—electromagnetism. Resonance effects in the radar cross-sections of conducting and dielectric bodies are as abundant and familiar as they are for the acoustic case of sonar cross-sections. The literature in this area is quite extensive. For instance,

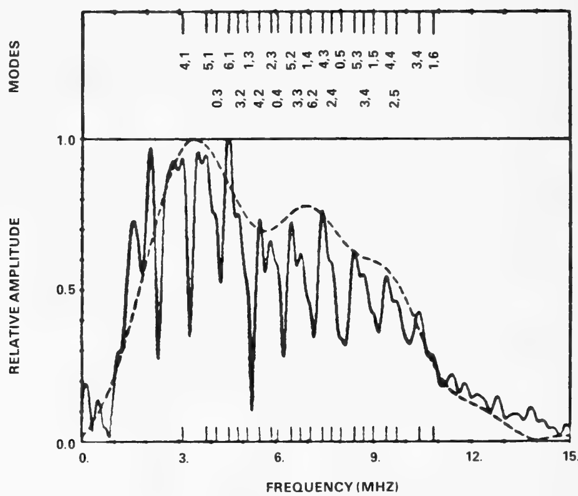


Fig. 4 *Ultrasonic resonances.* A compressional wave incident upon a water-filled cylinder in an aluminum medium is backscattered (θ = π) into another compressional wave. The form-function (f^{pp}) for this process is displayed versus frequency: (——), experiment; (----), spectrum of the incident pulse. (From Ref. 15) Various resonance modes are identified in the displayed power spectrum.

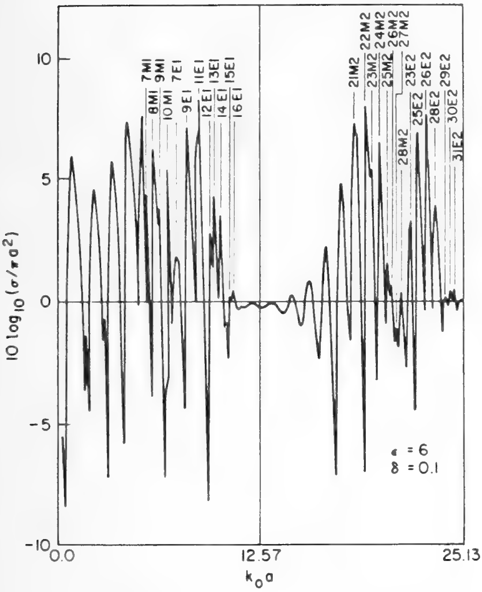


Fig. 5 *Radar resonances.* Radar cross-section (dB) of a perfectly conducting sphere coated with a masking layer of dielectric material, in the (non-dimensional) frequency band $0 \leq k_o a \leq 25.13$ $(=8\pi)$. Resonance oscillations are identified for various TE and TM modes. (From Refs. 18 and 19).

backscattering from a perfectly conducting cylinder (of radius a_0) coated with a layer of dielectric material was studied in Ref. 17, in 1957. The normalized cross-section versus non-dimensional frequency can be displayed for various thickness and composition values in the dielectric coating layer. The resonance peaks shift with thickness and composition changes in the dielectric coating. A general theory was developed which agrees with the experimental observations, however, no fundamental analysis of the resonances was performed here. In a similar study in 1964, a conducting spherical core covered with a layer of dielectric material was analyzed by Rheinstein.[18] Its radar cross-section (RCS) was obtained by classical means without a fundamental study to sort out the resonances present. A resonance scattering analysis[19] of this particular work was carried on later, in 1980 (see Fig. 5). It showed how RST could be used in this instance to: (a) identify the object, even though it is coated, since the composition of the dielectric layer can be extracted from the wiggles in the RCS, in whichever frequency band one has access to and, (b) best mask the object or make its presence less apparent in spite of the fact that it is being illuminated since a well-chosen coating reduces the cross-sectional peaks by damping the material resonances. This analysis has served to model the echoes from a telecommunications satellite coated with a dielectric layer. It could also apply to any other large coated conducting object of spherical shape. Extensions of this manner of treatment to other geometrical shapes, coated or bare, are also possible.

II. Some Noted Resonance Behaviors

In all of the diverse physical processes described above, natural resonances occur. Consequently, there is a common bond between them since all could be analyzed using RST. This would yield important information about their shape and material properties. Other examples come to mind, all of which display notable resonance features, and for which a fundamental, unifying analysis has yet to be performed. We will briefly discuss some of these "future possibilities" here.

Wave propagation through the Earth—in an earthquake, for example—immediately brings out the resonances of the Earth itself. In Geophysics, the Earth is usually modelled as a large layered, elastic sphere. Even without the layering, the analysis is quite complicated and it leads to the so-called radial and spheroidal vibrations.[20] More recent works[21,22] have analyzed and displayed theses vibrational spectra from novel viewpoints. The graphs in Ref. 21 show some of the earth's radial and spheroidal eigenfrequencies in the MHz region, caused by various types of surface tremors. Resonance features are clearly evident in the graphs presented in these papers. Some of these features were examined with RST in Ref. 22. This work continues.

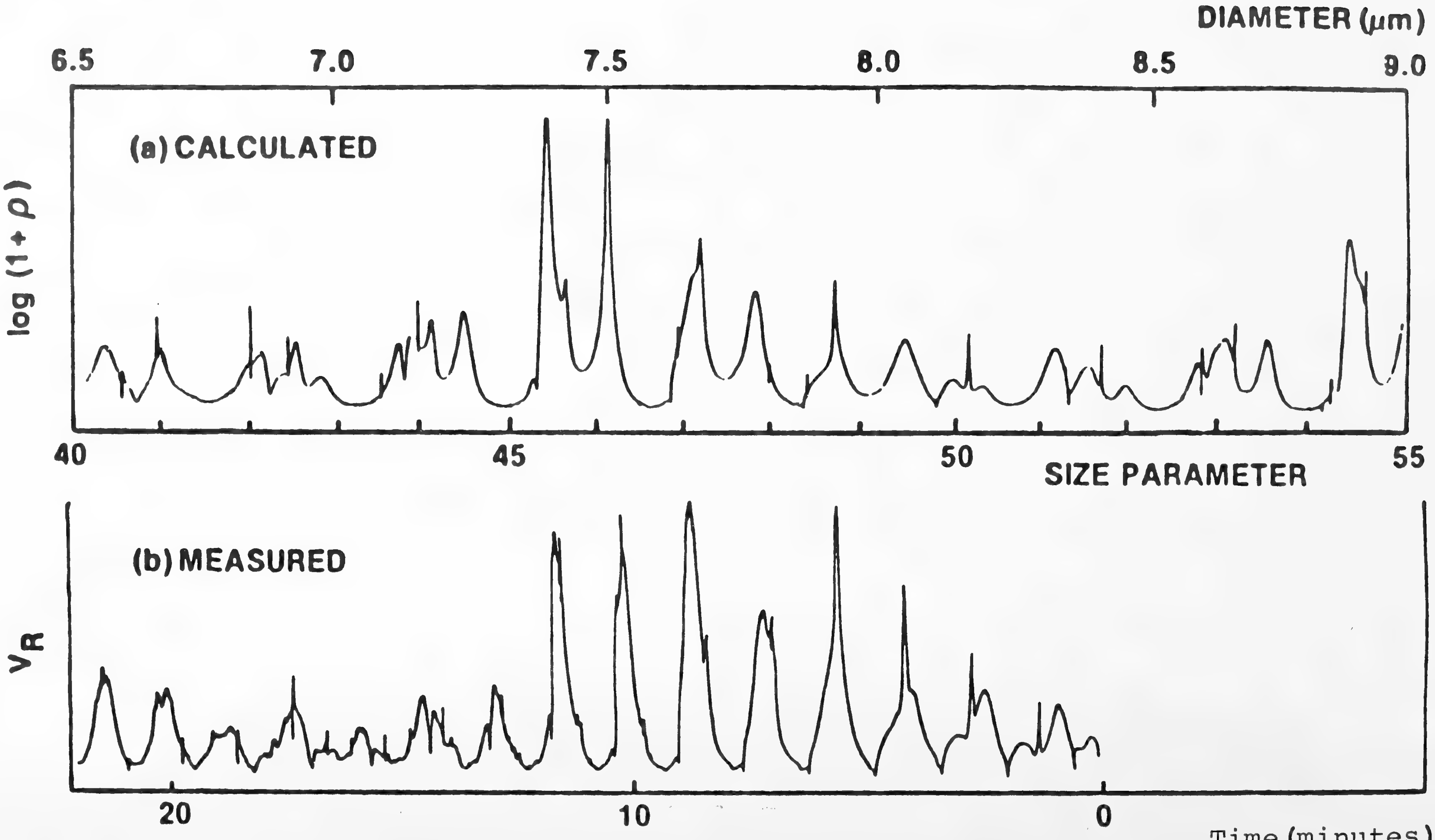


Fig. 6 *Optical resonances*. Incident polarized laser light ($\lambda = 514.5$ nm) is scattered through 90° by glycerol droplets. The polarization of the scattered intensities both parallel to and perpendicular to the incident ray's direction are measured: $V_R = I_{\parallel}/I_{\perp} \equiv \rho$. (From Ref. 25). (a) Theoretical plot of $\log(1+\rho)$ versus diameter (2a) for a lossless droplet of refractive index 1.47. The size parameter, ka ($= 2\pi a/\lambda$), is also presented. (b) Plot of measured V^R versus droplet evaporation time.

Another more localized geophysical problem exhibits resonance features with a growing RST connection. When a sound wave is incident on a layered ocean bottom, the reflection coefficient exhibits certain losses that depend on the angle that the incident pulse makes with the seabed.[23] The angle dependence of this bottom-loss exhibits a marked resonant behavior. Some of these features have been analyzed with RST in Ref. 24. This work studies lossy multilayered configurations, analogous to, but not quite the same as, stratified ocean bottoms. Thus, the RST-analysis still has to be extended to yield a more accurate model for ocean bottom reflections.

Resonance scattering of light is useful, among other applications, for the high resolution sizing of liquid droplets in aerosols or in clouds.[25] Existing techniques can reach size resolutions of one part in 10^5. Investigations have been made by shining laser light at 90° on individual droplets and polystyrene spheres in the 6.5 to 11.5 μm diameter range. Levitated single droplets, evaporated and non-evaporated, have been studied, as well as spherical and non-spherical single or multiple droplets. The unprecedented size resolution resulting from this method finds application in the measurement of diffusion coefficients and in studies of areosol growth and evaporation.

Figure 6, taken from Ref. 25, displays spectral resonances useful for particle sizing, and compares prediction with observation which appear to agree. Although these resonances have been analyzed, the emphasis has been on the determination of the sphere's size. The problem remains to extract information on size distributions, concentrations and overall material properties from the structure of resonances in the scattered returns. This seems to be a task perfectly suited for RST.

Nuclear resonance reactions have received considerable attention since the early work of Breit and Wigner.[26] Of particular interest, is the photonuclear giant resonance in Si^{28}. Plots of the yield from the reactions Al^{27} (p,γ) Si^{28} and Si^{28} (γ,n) Si^{27} are shown in Figure 7 and taken from Ref. 14. The cross-sectional plots contain the rapid oscillations typical of resonant behavior. Additional evidence of resonant nuclear behavior was analyzed in $C^{12} + C^{12}$ scattering studies carried out in 1980 (Ref. 27).

All these articles display cross-sectional plots (versus energy) as predicted by theory[28] and as observed in measurements.[27] The general connection between the resonant behavior in these plots and those of analogous disciplines, however, remains unexploited and largely unexplored.

It is interesting to note that the original development of the RST was in fact an extension of Breit and Wigner's work in quantum theory to a classical scattering situation. Perhaps we can bring these ideas around full circle and find new insights into the problems of nuclear physics from

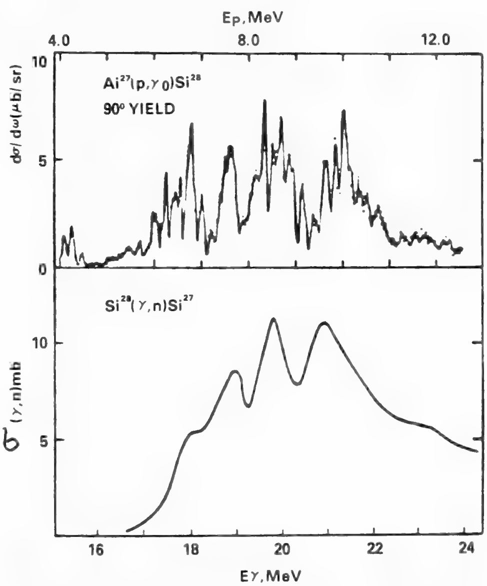


Fig. 7 *Nuclear resonances. Top:* The reaction differential cross section for ground state energy photons emitted at 90° to the incident protons direction is plotted versus proton energy. The cross section units are microbarns (10^{-30} cm^2) per unit solid scattering angle (steradians). *Bottom:* Total reaction cross section in microbarns (10^{-27} cm^2) as a function of the incident photon's energy.

a technique that began there, by studying a properly chosen acoustic or electromagnetic analogue.

III. Future Paths

With so many possible applications being investigated, research into resonance scattering is growing ever more exciting. Advances in one field are quickly transferable to another, since the governing equations and the general methodology have so many similarities. One can see that advances in underwater acoustics can be carried over to areas such as nuclear physics—the field first investigated with a resonance expansion. Extensions of the theory appear constantly with the particular and peculiar details of each application requiring individual and often considerable effort.

Scattering processes in the resonance region are certainly the hardest to study since in this region one cannot take advantage of any low or high frequency asymptotic approximation. Exact solutions developed for this region can be extended to the far limits of the respective spectra to yield novel ways of looking at resonance processes everywhere. The ultimate goal is a broadly useful analytical method which is both informative and esthetically pleasing. This should result in a macroscopic spectroscopy applicable to objects of all sizes interacting with all types of radiation in all conceivable spectral bands. Also, there is now hope that the inverse scattering process will be amenable to interpretation and solution. Techniques for target identification and active signature analysis will prosper. We look forward to sharing this excitement with the many professionals in diverse fields who serve to benefit from this common goal.

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Fatty Acid Synthase: A Protein Having Many Catalytically Active Domains

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ABSTRACT

Fatty acid synthesis requires the participation of a protein, the acyl carrier protein (ACP) and six or seven different enzymes. In prokaryotes these proteins are separable and monofunctional. Such an organization of the proteins is called Type II. In animal tissues and yeast, the same enzyme activities are located on only one or two peptide chains. These polyfunctional enzyme system is referred to as Type I. Plants have retained Type II enzyme systems which are confined to plastid-related organelles. This lends support to the bacterial origin of these organelles.

Type I fatty acid synthase is believed to have originated by the fusion of the ancestral genes encoding Type II enzymes and ACP. A comparison of the distribution of the various enzymatic loci in yeast and vertebrate synthase suggests that the diversion during the course of their evolution occurred by independent fusion.

Living organisms are able to perform incredible feats of chemical activities required for their survival because these activities are mediated by enzymes which are extremely efficient catalysts. The efficiency of these catalysts is manifest in their increasing the rates of chemical reactions several thousand- or even millionfold, and in exhibiting extreme specificities with regard to their substrates and the reactions they catalyze. Hence, virtually no product other than the desired ones are obtained during the course of the reaction. The metabolic pathways that constitute the catabolic and anabolic reactions involve a reaction sequence in which a starting precursor molecule undergoes a sequence of reactions in which the product of the first reaction becomes the substrate of the second reaction and the product of the second reaction the substrate of the third reaction and so on until the desired final product is obtained. At each step a single chemical event occurs. This might be the addition of a particular group or the removal of one, cleavage or the formation of one specific bond or a simple rearrangment of atoms or groups of atoms within the molecule. Underlying the complex network of chemical reactions, constituting the various reaction sequences, shown in the metabolic charts adorning a biochemist's office, there is a corresponding network of enzymes. The general rule

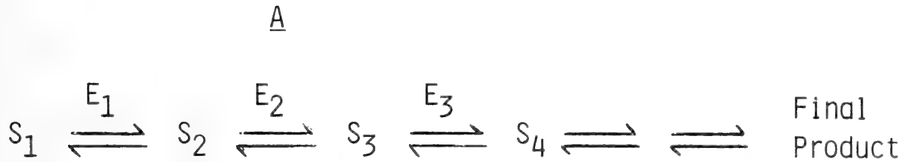


Fig. 1A. Metabolic reaction sequences in which the concerned enzymes (E_1, E_2, E_3) are separate entities.

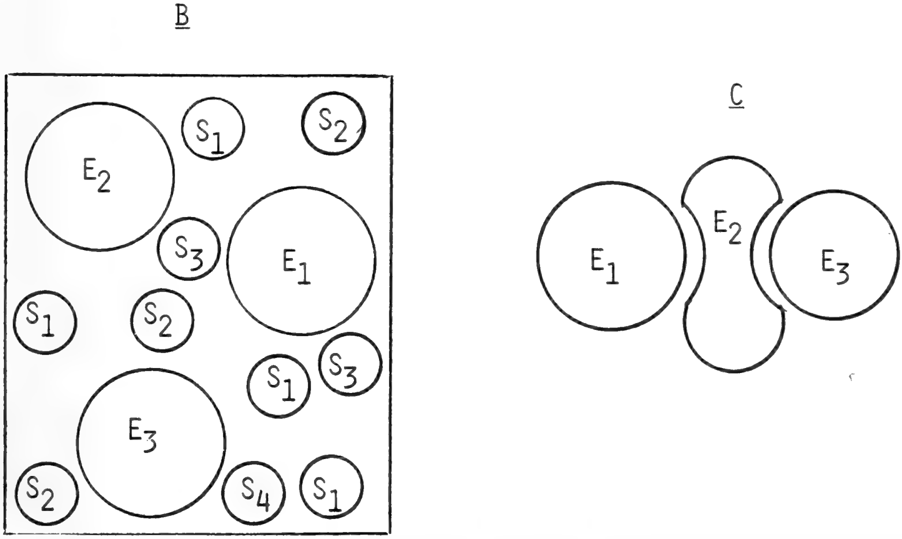


Fig. 1B. Schematic representation of (A) the soluble, separable, unaggregated enzymes catalyzing the reactions shown in Figure 1A; and (C) a multienzyme complex, of which pyruvate dehydrogenase (Figure 2) is an example, in which there is an aggregation of the separable enzymes.

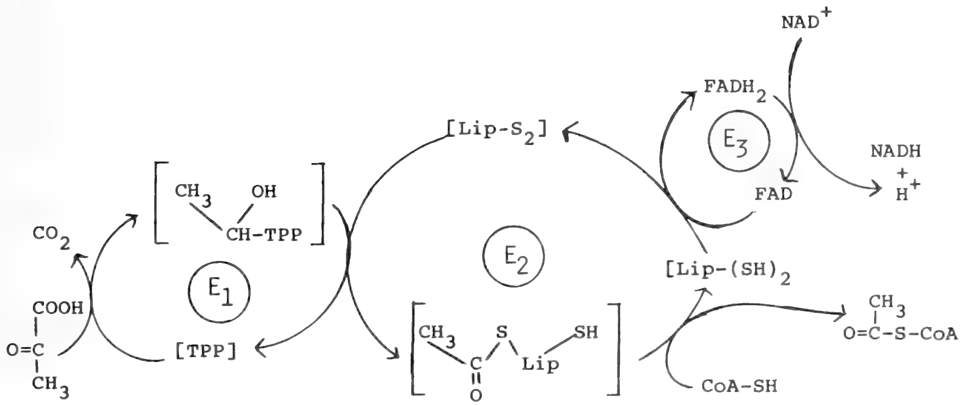


Fig. 2. Mechanism of action of pyruvate dehydrogenase. Three enzymes are involved. They are pyruvate dehydrogenase (E_1), dihydrolipoyl transacetylase (E_2) and dehydrolipoyl dehydrogenase (E_3). The complex, an aggregate of these enzymes, each containing several peptide chains, has a particle weight of several million daltons.

is, one enzyme catalyzes only one reaction. The oxidation of glucose to lactic acid (glycolysis) occurs in ten steps and requires ten different enzymes.

Soluble, Separable Enzyme System

In this system (Figure 1A) the product of the first reaction, S_2, can be presumed to move about in the intracellular space available until it encounters E_2, the enzyme catalyzing the second reaction resulting in S_3 which has to find E_3 (Figure 1B). The efficiency of the overall reaction sequence under this system would depend upon the catalytic efficiency (k_{cat}) of the various enzymes and the steady state concentrations of all the intermediates. The requirement for coenzymes and other cofactors in some of the reactions is another complication. Enzymes catalyzing the reactions of glycolytic and citric acid cycle are examples of such a system.

Multienzyme Complexes

The efficiency of a reaction sequence would be increased considerably if the enzymes catalyzing consecutive reactions are aggregated, or associated, so that the product of a particular reaction finds the enzyme catalyzing the subsequent reaction right next to the first enzyme. The intermediates in such a system would be transferred from one enzyme to the next, "bucket brigade" fashion. In effect, this increases the local concentration of each of the intermediates immensely and thereby increases greatly the efficiency of the overall process. Such an arrangement is found in several enzyme systems. One of the most thoroughly studied is pyruvate dehydrogenase which oxidizes pyruvate according to the following equation:

$$\underset{\text{Pyruvic acid}}{CH_3-\overset{O}{\overset{\|}{C}}-COOH} + CoA-SH + NAD^+ \longrightarrow \underset{\text{Acetyl-CoA}}{CH_3-\overset{O}{\overset{\|}{C}}-S-CoA} + CO_2 + NADH + H^+$$

This reaction occurs in five discrete steps (Figure 2) and requires three different enzymes and thiamine pyrophosphate (TPP), enzyme-bound lipoic acid (Lip S_2) and enzyme-bound flavin-adenine dinucleotide (FAD) as cofactors. E_1, the dehydrogenase decarboxylates pyruvate, it releases CO_2 but keeps the acyl product formed covalently linked to TPP which itself is bound to E_1. The subsequent step involves the transfer of the acyl group to E_2-bound lipoate which requires the reduction of lipoate and oxidation of the acyl group. E_2, then transfers the acetyl group formed to CoA of the medium but this leaves lipoate in the reduced state. FAD containing E_3 oxidizes lipoate to enable it to accept another acyl group from E_1 while NAD^+ of the medium is used by E_3 to oxidize the reduced form of FAD in order for it to function as an oxidant of reduced lipoate. The point to notice is that the different intermediates are transferred from the one enzyme to another and are not released into the medium. The three enzymes concerned while existing as a complex can be dissociated from each other and can function independently of each other provided the appropriate substrates are made available.[1]

A variation of the association of proteins catalyzing consecutive reactions is the respiratory enzyme complex that carries out electron transport with the concomitant formation of ATP. In this system, the aggregates of the different proteins are held together by their being embedded in the membranes of the mitochondria. Being aggregates these enzymes are also separable but because of their natural association with membranes special handling is required.

An entirely different kind of complex is that of aminoacyl-tRNA synthetase enzyme systems found in eukaryotic species. Several synthetases, specific for as many as seven to ten amino acids, occur as aggregates.[21] These aggregates carry out parallel reactions, rather than sequential reactions, and the enzymes concerned appear to be functionally independent. The biochemical significance of this type of organization of enzymes is at present not clear.

Enzymes with multicatalytic sites.

There are enzymes which catalyze more than one chemical reaction and which, therefore, must possess more than one catalytic site. A good example is the DNA polymerase that carries out the template-directed DNA synthesis in the $5' \rightarrow 3'$ direction but which also possesses exonuclease activity for clearing the path and for "proofreading and editing" mismatched bases to ensure fidelity of DNA replication. The exonuclease activity resides on the same peptide chain and in the native, folded state must be near the polymerization site.[2] The nuclease activity can be excised enzymatically.

Dual Organization of enzymes catalyzing de novo *fatty acid synthesis.*

Fatty acid synthesis occurs according to the following equation:

$$\underset{\text{acetyl CoA}}{CH_3\overset{\overset{O}{\|}}{C}-S-CoA} + 7\ \underset{\text{malonyl-CoA}}{\overset{COOH}{\overset{\diagdown}{CH_2}}-\overset{\overset{O}{\|}}{C}-S-CoA} + 14\ NADPH + 14\ H^+ \longrightarrow$$

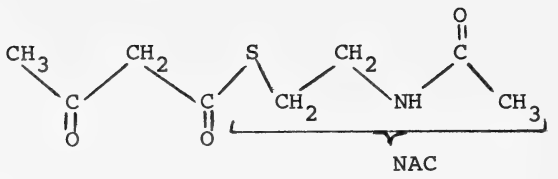
$$+ \underset{\text{Palmitic Acid}}{CH_3-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-COOH}$$

$$+ 8\ CoA-SH + 6\ H_2O + 7\ CO_2$$

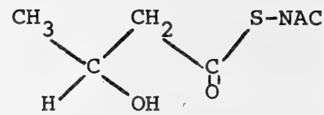
Early attempts to isolate the intermediates in the process in order to elucidate the synthetic pathway failed because, as it was later realized, the acyl intermediates were covalently bound to a relatively large-molecular protein.[3] The enzyme from both yeast and pigeon liver, the two sources of the enzyme in these studies, was very specific for acetyl-CoA and malonyl-CoA and exhibited little reaction with suspected intermediates, like acetoacetyl-CoA, butanoyl-CoA or hexanoyl-CoA. These investigations also failed to resolve the enzyme into smaller components with partial activities.

Two strategies were adopted for the elucidation of the reaction sequence. Lynen and his coworkers, after having obtained evidence that the acyl intermediates were bound to the enzyme via thiol ester bonds, employed acyl thiol esters of N-acetylcysteamine as model substrates.[3] Their structures are shown in Figure 3.

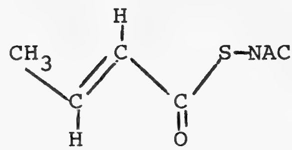
If relatively high concentrations of the model substrates and the enzymes are used it was possible to "cheat" the enzyme into binding the substrate at the active site long enough for a specific reaction to occur at a measurable rate. For instance yeast synthase would reduce acetoacetyl-NAC (Figure 3A) and crotonyl-NAC (Figure 3C) to 3-hydroxybutanoyl-NAc and butanoyl-NAc, respectively, in the presence of NADPH and would dehydrate β-hydroxybutanoyl-NAc (Figure 1B) to crotonyl-NAc. With such substrates only individual partial reaction because the product would diffuse away and its concentration would be too low



Acetoacetyl-N-acetyl cysteamine (NAC)
(A)



β-hydroxybutanoyl-NAC
(B)



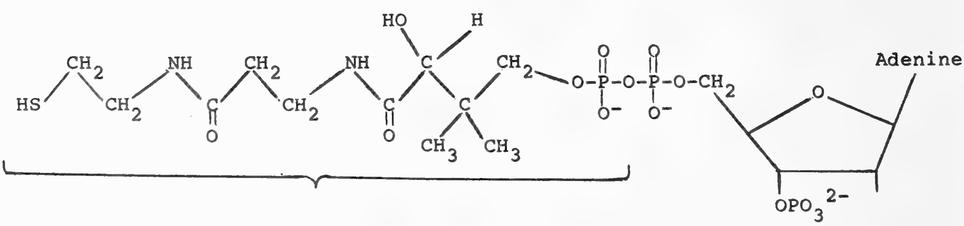
trans-crotonoyl-NAC
(C)

Fig. 3. Structures of model compounds of N-acetylcysteamine.

would occur and not the overall reaction for the subsequent reaction.

An alternate strategy employed by Vagelos and his group of workers was to attempt to fractionate the enzyme system from a prokaryote, a simpler organism such as *E.coli,* into component enzymes. In this they were successful. The fatty acid synthesis by this system was found to require a heat and acid stable protein of relatively low molecular weight ($M_r \sim$ 10,000) which bound the acyl intermediates. Characterization of this protein, which was named acyl carrier protein (ACP), revealed the presence of a prosthetic group, 4′-phosphopantetheine, which was bound to ACP via an ester linkage to a specific serine residue.[4] 4′-Phosphopantetheine is also the tail portion of coenzyme A, the carrier of many of the reactive acyl groups in biological systems. The structure of the prosthetic group and its relationships to the rest of the molecule of coenzyme A is shown in Figure 4.

Following the discovery of ACP, all of the enzymes concerned were purified and the reaction sequence was rapidly established. This is shown in Figure 5A. This sequence is similar to that deduced for yeast enzyme using model substrates by Lynen and coworkers.[3] After the first round of six reactions requiring six enzymes the chain lengthening continues with the addition of two-carbon units successively, employing the enzymes in reactions 3–6 until palmitoyl-ACP is formed.



4'-Phosphopantetheine

Fig. 4. Structure of coenzyme A showing the 4′-phosphopantetheine prosthetic group of acyl carrier protein.

5.A.

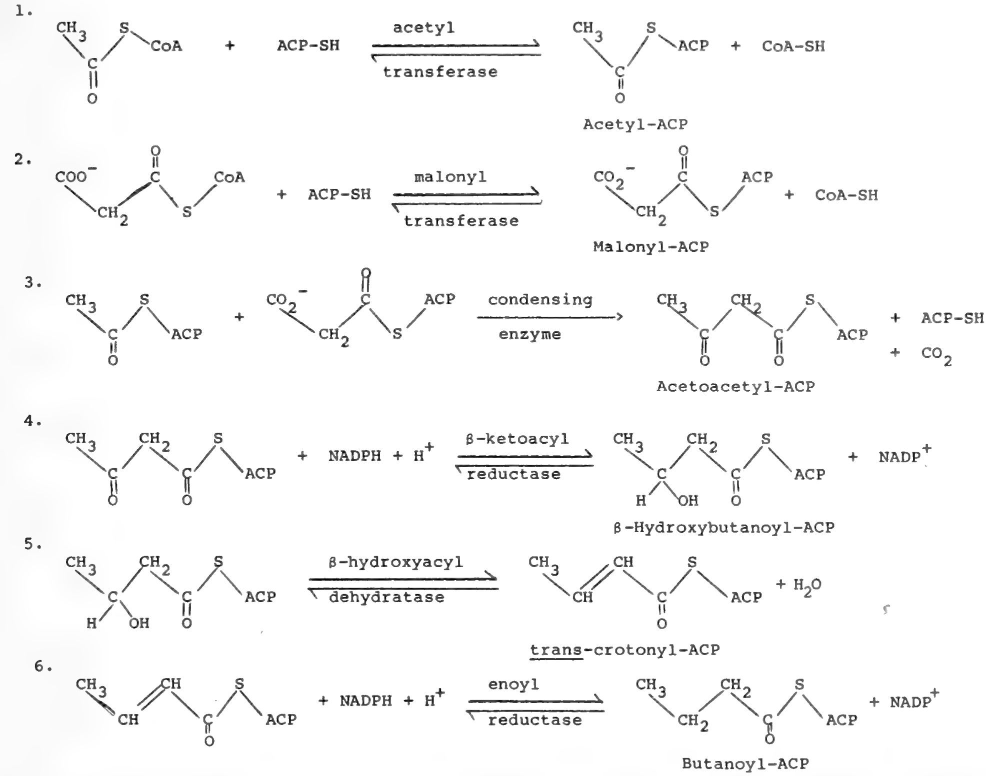


Fig. 5A. Reaction sequence for the *de novo* synthesis of fatty acids. Successive reactions in the first round of reactions is shown. Butanoyl-ACP formed condenses with a mol of malonyl-ACP (Reaction 3) and reactions 4–6 are repeated. This process is repeated until the 16-carbon palmitic acid is formed.

5.B.

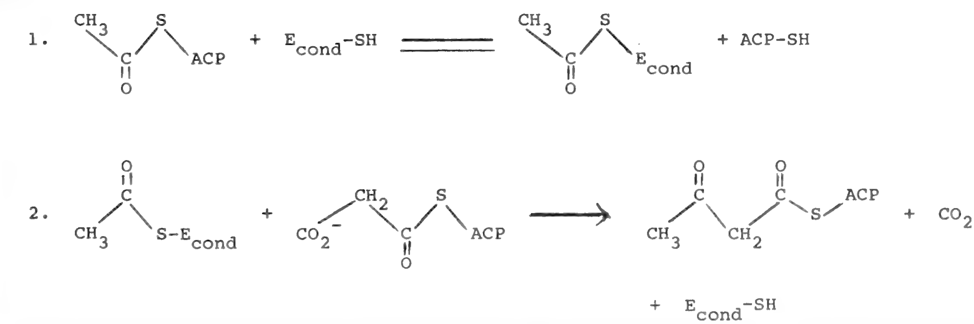


Fig. 5B. Mechanism of the condensing reaction. This reaction occurs in two steps. Acetyl (or a saturated acyl) group is transferred by the enzyme to one of its own specific cysteinyl SH group. This is followed by condensation with an ACP-bound malonyl group so that the β-ketoacyl group formed is now bound to ACP via its pantetheinyl SH.

Such a dissociable enzyme system was not found in yeast, avian and mammalian tissues. Yeast enzyme had a molecular weight of 2.1×10^6. Fatty acid synthase from various animal tissues were similar in size with a molecular weight of about 500,000. The reaction sequence by which the acyl chain is elongated is also similar which indicates the requirement for the same catalytic activities. These enzymes also contained 4′-phosphopantetheine as prosthetic group and its role in the binding of incoming malonyl goup and of the reactive acyl intermediates were similar to *E. coli* and yeast enzymes.

Classification of Fatty Acid Synthase.

Two distinct types of organization of the enzymes constituting the fatty acid synthesizing system is, thus, found in nature. They have been called Type I and Type II by Bloch.[6] Type I consists of the organization of the various enzymes into a tight complex, not amenable to dissociation into individual enzymes. This type is found in animal and insect tissues, yeast and certain bacteria. Fatty acid synthase, Type II, characterized by the component enzymes being separable, is found in prokaryotes, e.g., *E. coli,* and most bacteria. It is interesting that plants, although eukaryotic in nature have Type II fatty acid synthase.[7] The exclusive location of the enzymes in proplastids, plastids and chloroplasts has been taken as evidence that supports the prokaryotic origin of these organelles and the symbiotic relationship between them and the host cells. It would appear that Type I synthase is cytosolic and Type II is organellar in location. The chloroplast containing green alga, *Euglena gracilis,* is endowed with both types of the enzyme system. Type I is present in the cytoplasm and Type II in the chloroplasts. It is interesting to note that Type II enzyme system is induced when these organisms are grown in light and is absent when grown in the dark.[8] It appears highly likely that Type II synthase in plants has all the constituent enzymes aggregated in a loosely-associated complex in the confines of the organelles and that it is the disruption of the organelles in the course of the preparation of the enzymes, that disaggregates the complex.[7]

Type I Fatty Acid Synthase.

The demonstration of the various partial reactions by the enzyme complex isolated from yeast and animal tissues and the failure to dissociate the complex into component enzymes led Lynen to propose a model, by analogy with pyruvate dehydrogenase, in which ACP, with a 20 Å long 4′-phosphopantetheine arm, was pictured as constituting a hub around which the various enzymes were arranged in the order necessary to carry out the reaction sequence.[9] This is the model currently shown in all the textbooks. The prosthetic group with the reactive acyl group is pictured as swinging from the catalytic site of one enzyme to the next successively to complete a round of reactions. The saturated unsubstituted acyl group formed after one round of reactions is transferred to a specific cysteinyl-SH of the condensing enzyme. The free SH group of pantetheine then accepts a malonyl group. Condensation occurs between the acyl group at the cysteinyl site and the malonyl group (Figure 5B), which is followed by another round of reactions. This process is repeated until chain lengthening ceases by a mechanism still not understood.

Subunit compostion of Type I Synthase.

Efforts to dissociate the enzyme complex from animal tissues was finally met with partial success. The 500,000 molecular weight species of the enzyme complex yielded a species with 250,000 molecular weight in buffers of low ionic strength.[10,11] These could be reassociated with the restoration of full activities. So convinced were the workers of the multienzyme nature of the complex that the 250 kDA species were considered subcomplexes, more loosely associated with each other than the components of each of the subcomplex. Gradually evidence began to accumulate, however, that the two 250 kDa species formed upon dissociation of the synthase were identical and consisted of a single peptide chain. This, naturally led to the concept that the various catalytic activities, representing each of the partial reactions, were distributed on the same peptide chain.

Yeast fatty acid synthase, of molecular weight, 2.1×10^6, had an entirely different kind of organization. It consists of two different peptide chains and the various partial activities were distributed on these two chains. To complicate matters even further there are six copies of each chain.[12] The subunit composition of yeast and animal synthase are represented as $\alpha_6\beta_6$ and α_2 respectively.

Comparative Aspects of Fatty Acid Synthase, Type I.

While in all essential features the fatty acid synthase from various animal tissues are very similar there are some striking differences. 1) Acetyl-CoA was recognized early as the specific primer of the overall reaction. Higher homologues of acetyl group yields poor reaction with yeast and avian liver enzyme. The enzyme from mammalian tissues was later found to utilize butanoyl-CoA more efficiently than acetyl-CoA.[13] 2) Starting with acetyl-CoA, palmitic acid was the main product with yeast and avian enzymes. The enzyme from mammalian sources, on the other hand, produces a high proportion of butanoic acid. This derailment of the C_4 acid intermediate is attributed to the lack of specificity of the acyl transfer reactions.[13] Butanoyl group leaves the pantetheinyl SH group by being transferred to CoASH. Butanoyl-CoA produced in this manner, most probably, accounts for the butanoic acid content of the butterfat of ruminants. 3) A lack of specificity with regard to the acyl group transfer by bovine mammary synthase also accounts for the high rates of reduction of acetoacetyl-CoA and crotonyl-CoA observed with this enzyme. This enabled us to characterize each of the partial reactions using esters of CoA at natural concentrations.[11,14] Employment of model substrates was useful to demonstrate the occurrence of a reaction but not to characterize it. 4) Goose uropygial fatty acid synthase is able to form multibranched chain fatty acids from acetyl-CoA as primer if methylmalonyl-CoA is used for chain elongation.[15] 5) Yeast enzyme transfers palmitoyl group upon termination of chain elongation to coenzyme A.[12] Animal synthase, on the other hand, hydrolyzes palmitoyl group from the prosthetic group to form free palmitic acid. This requires the presence of an additional enzyme, a thioesterase in the complex.[16] 6) There is a separate transferase for acetyl and malonyl groups in the yeast enzyme but the same transferase serves to transfer both groups in the vertebrate enzyme.[17]

Multicatalytic function of fatty acid synthase I.

The resistance of the 250 kDa subunit of fatty acid synthase from animal tissues to dissociate into smaller peptides, despite treatment with chemicals that disrupt all chemical interactions except the covalent bonds, led to the recognition that all the catalytic activities reside on the same peptide chain. Such a concept and the identical nature of the two peptide chains finally gained acceptance. This implied that the five or six different chemical activities, necessary for the addition of each 2-carbon unit, reside on different domains of the relatively large peptide chain.[12]

The creation of a functional map began by the cleaving off of the thioesterase by treatment with trypsin.[16] A 29 kDa active thioesterase was obtained which proved to be the carboxyterminal end region of both the chains. Using the approach of limited proteolysis and employing different enzymes Wakil and coworkers,[12] in

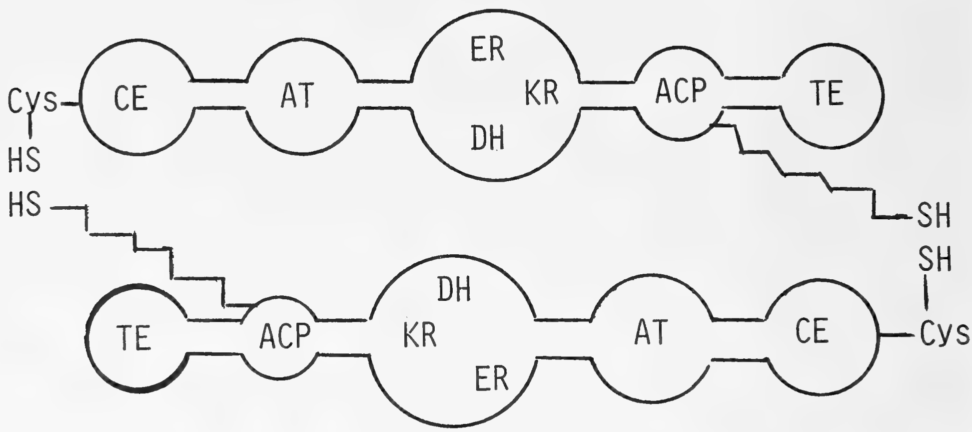


Fig. 6. Functional map of fatty acid synthase of animal tissues. Each subunit is juxtaposed in a head-to-tail manner. The domains representing the different activities are: acyl carrier protein shown with its prosthetic group (ACP); condensing enzyme (CE, reaction 3); acetyl- and malonyl-transferases (AT reactions 1 and 2); β-ketoreductase, dehydratase and enoyl reductase (KR, DH and ER, reactions 4, 5 and 6 respectively). For the reaction numbers refer to Figure 4. The different domains are not drawn to scale. Adapted from the results of Wakil *et al*[12] and McCarthy and Hardie.[17]

Houston, Texas, and Hardie and colleagues[17] in Dundee, Scotland, have constructed a functional map of the synthase identifying the various partial enzyme activities. Both groups have arrived at similar conclusions. The map is presented schematically in Figure 6. The two subunits are held by non-covent forces in a head-to-tail arrangement such that ACP domain of one subunit is juxtaposed against the condensing domain of the adjacent subunit. This would facilitate the condensing reaction (Figure 5B) occurring at both ends of the enzyme molecule. The formation of β-ketoacyl group is followed by reactions 4, 5 and 6 sequentially (Figure 5A) to complete one round of reactions. The details of the reactions and the arrangement of the different domains involved are yet to be determined.

Occurrence of fatty acid synthesis in living organisms.

Fatty acid synthesis is an essential feature of all dividing cells. The *de novo* synthesis provides palmitic acid from which the various fatty acids of the membranous lipids are derived. The fatty acid synthase is absent, or is present in extremely low levels, in fully transformed cells except certain specialized cells. All vertebrates are able to store excess food intake in the form of fat (triacylglycerols) to be used at times of need. Fatty acids for the formation of this concentrated form of "stored" energy occurs primarily in liver, whence it is exported to the various site for deposition. Besides liver, lactating mammary gland is extremely active in the synthesis of fatty acids and its conversion to milkfat in order to enrich milk with a high energy dietary product.

The level of hepatic fatty acid synthase can be easily manipulated by dietary regime. Starvation for just two days reduces the synthase activity to barely detectable levels. It has been established that the enzyme is in fact degraded and not just inactivated. Refeeding a starved animal with a high carbohydrate diet results in a surge in the synthesis of the enzyme, reaching 3 to 4 times the normal level within forty-eight hours.[18] This feature has been exploited to obtain large quantities of the enzyme for purposes of purification. Lactating mammary enzyme, on the other hand, is less sensitive to dietary manipulation.

Genetic Implications of the Multicatalytic Function of Type I Synthase.

The presence of type II fatty acid synthase in an organism necessitates the encoding of the various enzymes in different genes, the expression of which will have to be closely synchronized to ensure the proper ratio of the enzymes. Type I system has the advantage over Type II system in that all the activities are encoded in only one or two genes. Control of the expression of the gene(s) is, presumably, facilitated.

A comparison of the aminoacid sequence of ACP of various bacterial, plant and animal origin shows striking homology indicating a common ancestral gene from which the ACP genes of modern species evolved.[19] Although data are still more limited regarding the other enzymes or domains they do suggest similar homologies.[19] These observations constitute the basis for the current hypothesis that the respective enzymes of the system have also common ancestors and which were monofunctional (Type II). During the evolution of fungi and animals, fusion of genes occurred to form polyfunctional peptides. The encoding of the different proteins in two genes in the fungi and one gene in the animal organisms suggest that a divergence occurred during their evolution by two independent processes of gene fusion rather than by one consecutive process.[20] The order of the arrangement of the loci of the different domain in the two subunits of yeast synthase supports this concept.

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Dental Alteration in Prehistoric Ecuador A New Example from Jama-coaque

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ABSTRACT

A recently discovered prehistoric skull of Jama-coaque culture from Manabi, Ecuador shows a pattern of incised lines on seven of the anterior maxillary teeth. This example of dental incision is unique in South America and has been documented previously in the New World only in Mexico.

The practice of dental alteration in the prehistoric New World includes techniques of drilling, filing, chipping, producing designs ranging from filed points and incised patterns to drilled holes containing stone insets. Romero[1] has documented over 127 types, mostly originating in Classic and Post-Classic Mexico.

In South America, dental mutilation by chipping occurs only in historic times, and appears to have been introduced by Blacks. Prehistoric dental mutilation in South America outside of Ecuador consists only of filing, with published examples of teeth filed to points from Argentina, Bolivia, and Chile.[2] In prehistoric Ecuador, mutilation by filing also occurred, but in addition, examples of dental inlay have been reported that closely resemble those reported from Mexico. As early as 1909, Saville called attention to the early Spanish accounts of Zarate and Gomara which mention that when they explored the area of Atacames on the north coast of Ecuador, they observed Indians with "their faces sown with gold nails."[3] Saville[3] also reported skulls found in the Atacames area with small disks of gold set into circular drilled holes in the anterior teeth and one skull with wide plates of gold inset into the labial surfaces of the maxillary teeth.

In 1912, Joyce[4] illustrated a skull from the Atacames collection of the British Museum which shows drilled circular perforations in seven anterior maxillary teeth, with some still containing gold insets.

Estrada[5] indicates that skulls with "dientes con oro" were recovered from Elisita and La Tolita, but provides no detailed descriptions.

Evans and Meggers[6] provided illustrations and descriptions of examples of dental decoration from the sites of Elisita (G-M-5, Guayas Province), Atacames, and La Piedra on the Rio Esmeraldas in Esmeraldas Province. They note that the form of some of the dental inlays is similar to those reported from Mexico, especially from the state of Oaxaca. An important difference is that the Mexican inlays were mostly of pyrites, jadeite, or turquoise, while those from Ecuador are all of gold. They argue that the custom suggests contact between Ecuador and Mexico sometime during the Integration period, not earlier than A.D. 500–600. This comparison was made earlier by Saville[3] and by Stewart[2] who traced the form of dental mutilation to the Mayan area.

Carlos Zevallos Menendez[7] provides a summary of dental mutilation in Ecuador. Within this article he reports additional examples of isolated teeth with gold insets recovered during his excavations in the Chanduy Valley. He also describes a mandible excavated by Jorge Marcos at the site Congrejitos that displays small gold insets in the incisors, canines and premolars. A photograph of the mandible in site is provided by Marcos.[8]

All of the examples mentioned above were found in skulls originating from young adults who had died at a young age, before much of the crown surface was lost through attrition. An exception was reported by Ubelaker[9] from the Guayas Province site of La Compañia on the Rio Babahoyo. Five anterior maxillary teeth were found in a mound urn burial dating from perhaps the 16th century. The teeth originate from an older adult, in which attrition has destroyed most of the crown surface. Each tooth displayed a single circular perforation at the junction of the crown and root, probably for the purpose of displaying inlays. The burial also contained extensive exotic artifacts suggesting the individual enjoyed considerable status.

In 1985, an articulated skull and mandible were brought to the attention of Olaf Holm, Director of the Museo Antropologico, Banco Central del Ecuador. The material had been found in the culture area of Jama-coaque near Manabi and is estimated to date between 200 B.C. and 800 A.D. The material was delivered to the Museo with the skull and mandible articulated and still embedded in the soil matrix. Several of the anterior teeth apparently had fallen out and had been rearticulated with adhesive to the approximate original locations, but in incorrect anatomical order (Figure 1).

On July 10, 1986, at the request of the Museo, the author carefully removed the skeletal remains from the soil matrix, cleaned all skeletal parts and teeth, and subsequently reconstructed them as much as possible. Analysis revealed a nearly complete skull and mandible of a young adult (Figure 2). Most cranial vault sutures were open and dental attrition was minimal, suggesting an age at death of between 28 and 34 years. The occipital shows marked flattening, strongly suggesting intentional cranial deformation. All teeth were present except the maxillary left premolars, and the mandibular

Fig. 1. Jama-coaque skull and mandible with incised teeth prior to cleaning and reconstruction.

Fig. 2. Jama-coaque skull and mandible after cleaning and reconstruction.

right canine and first premolar. None of the teeth present had carious lesions and deposits of calculus were absent on some teeth, but heavy on others.

Male sex is suggested by the presence of moderately large supra orbital ridges, deep grooves behind the mastoid processes and a mandibular gonial angle approaching 90°.

The only evidence of disease consists of porosity on the superior interior surface of both orbits. This "cribra orbitale" suggests the individual may have suffered from anemia.

Fig. 3. Incised maxillary teeth from Jama-coaque skull.

Seven of the anterior teeth display a series of incised lines on their buccal crown surfaces. The maxillary canines and incisors all show a series of intersecting incised lines of a cross hatch design (Figure 3). The right central mandibular incisor shows a single diagonal incised line on its buccal crown surface. All of the designs would have been visible through the mouth and clearly were made during life for aesthetic purposes. The anterior mandibular teeth show more advanced attrition than those of the maxilla. Thus, it is possible that the lower teeth may once have had more incisions, but lost them through attrition.

This type of dental modification is previously unknown in Ecuador and to the best of the author's knowledge, in South America as well. The design is very similar to a single example reported from Mexico by Romero.[10,11] The Mexican skull is a male from "entierro 17 de Xaloztoc, Edo. de Mexico, Preclasico Superior." Romero's[10] brief description is as follows: "Casi todo la extension de la cara anterior se encuentra ocupada por una serie de lineas entrecruzadas. Existe en incisivos laterales y caninos superiores, en combinacion con la forma anterior en los centrales . . . ," (Figure 4).

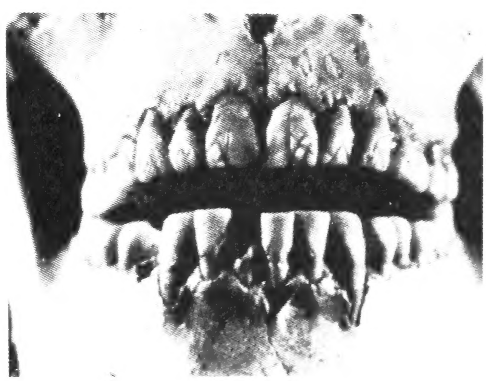

Fig. 4. Incised maxillary teeth from Preclassic skull from Xaloztoc, Mexico (from Romero, 1958: 45).

This newly discovered dental alteration suggests that methods of dental decoration and alteration in prehistoric Ecuador were even more varied than previously thought. The incised teeth also add yet another cultural trait shared by prehistoric peoples of Ecuador and Meso America.

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