thus closing the feedback loop. Their hypothesis suggests that biophotons originate from a delocalized coherent field within living matter. When a bioregulatory system is stressed, this is equivalent to a partially disintegrated system with a malfunctioning negative feedback. Gu and Popp review the theoretical research on the non-linear response of photon emission to external perturbation.

The last part of this multi-author review deals with photon emission in relation to disease. Phagocytes (macrophages and polymorphonuclear leucocytes) take an essential part in the defensive attempts of the host. In their article, Lilius and Marnila review the phagocytic activities from individuals under stress or disease. They conclude that photon emission capacity of phagocytes reflects remarkably well the pathophysiological state of the host. But what defence costs has the host to pay? Producing oxygen radicals is dangerous. Cells are unable to completely prevent these compounds from escaping their membranous compartments. Then the question arises as to how, in the diseased state, the chronically adapted cells behave with respect to photon emission. An interesting example is the photon emission of tumors and tumor cells. In the final contribution van Wijk and van Aken review the publications on photon emission in the field of tumor biology.

The assembly of the six contributions in this review offers the reader for the first time a more complete impression of photon emission in the field of stress. In the last decade the study of stress has moved to center stage in cell and molecular biology. In the past few years HSP’s have been the focus of investigations in many areas of cell biology. Several experimental data indicate that the increased production of oxygen-derived free radicals and other active oxygen species are directly or indirectly involved in the regulation of the expression of genes coding for stress proteins. We are beginning to discern the richness of information which can be retrieved from measurements of photon emission. This review on photon emission may offer new insights into the areas of stress and disease.

**Introduction**

Ultraweak luminescences emitted by living organisms at photon fluxes below ca. $10^4$ photons cm$^{-2}$ s$^{-1}$ have been detected for a wide variety of organisms which are not normally classified as bioluminescent. Reviews by Slawinska and Slawinski \cite{71,72} and by Cadenas \cite{8} provide useful overviews of this field, while Popp's multi-author review \cite{50} \textit{[Experientia 1988]} on biophoton emission gives detailed accounts of various aspects of these luminescences.

Two apparently distinct types of ultraweak photon emission have been reported in the literature, one in the visible region and the other in the ultraviolet region of the spectrum. The visible region luminescence is well established and it is generally argued that its source is excited singlet oxygen and excited triplet state carbonyls. These species are formed in vivo by processes such as lipid peroxidation, phagocytosis, enzymatic reactions and interactions of oxygen radicals (especially the superoxide anion) with some metabolites. These processes are often linked with oxidative stress. The ultraviolet (UV) luminescence has still not gained widespread acceptance despite its having a longer history than the visible region emissions.

In the 1920s Gurwitsch \cite{28,29} claimed that dividing cells emit a very weak UV luminescence which was termed mitogenetic radiation due to its alleged ability to stimulate cell division when incident on nearby cells. A review of mitogenetic radiation by Quickenden and Que Hee \cite{58} discusses some of the curious features of its history. The controversy surrounding mitogenetic radiation may account for the lack of acceptance of the ultraweak UV emissions. In addition, many of the modern studies of ultraweak photon emission have not been designed to detect UV light. In some cases \cite{18,22,69} the photomultiplier tubes used were sensitive mainly in the visible region of the spectrum, and in others \cite{33,42,67} the cuvettes used did not transmit UV light. Some recent studies \cite{23,35,73,74}, which have employed detectors sensitive in both the UV and visible region of the spectrum, have not carried out spectral determinations or have only monochromated the visible region of the spectrum and hence the extent of any UV component cannot be estimated in these cases.

This paper will review the spontaneous ultraweak photon emission from microorganisms with particular reference to the effects of temperature, chemical and oxidative stress.

**Early work on photon emission from microorganisms**

Very weak ultraviolet photon emission was the subject of frequent reports (over 500 papers) in the 1920s and 1930s under the heading of mitogenetic radiation, which largely originated with the work of Gurwitsch \cite{28,29}. Gurwitsch claimed that dividing cells emit very weak UV light which can itself stimulate division in other cells if incident upon them at an appropriate stage of their life cycle. The early method for measuring mitogenetic radiation from an emitting or 'sender' organism was by its ability to stimulate cell division in a variety of biological detectors such as yeast cultures, bacterial cultures and plant meristems. With biological detectors, the number of cells or cell divisions of the detector organism was compared to that of a control that was not exposed to the sender organism. A statistically significant difference was taken to indicate the mitogenetic effect. Mitotic stimulation was not substantially different when silica was placed between the sender and the detector, but no effect was observed when glass was interposed. It was thus concluded that the radiation consisted of UV light.

Gurwitsch's original mitogenetic studies used onion roots, but yeast and bacterial cultures either on agar plates or in liquid media were found \cite{8} to be the most reliable organisms for studying this effect. Organisms in their exponential phase of growth were relatively insensitive to mitogenetic stimulation, so lag phase or stationary phase organisms were used as detectors. However, exponential phase cultures were usually used as senders since emission was brightest during this period.

Although Gurwitsch is credited with the discovery of mitogenetic radiation, there were several earlier reports of similar phenomena. Thus Scheminzky \cite{70} was the first to report that some high energy radiation was emitted from various biochemical processes. He used cultures of yeast and bacteria to provide the biochemical processes and detected the emanations by means of photographic plates. This work was confirmed in 1918 by Ludwig \cite{45} who also used photographic plates to detect emissions from fermenting yeast. Ludwig found \cite{45}, moreover, that these emissions could penetrate optically opaque paper and were absorbed by protein matter, indicating that the emissions could be in the UV region. De Fazi and De Fazi \cite{14,15,16} studied the effects of UV light on yeast and found that fermentation was greatly stimulated by very weak UV radiation, or by very short exposure to higher levels of UV radiation.

Gurwitsch's work was supported by many Russian workers and several Western workers \cite{6,63,85}, but many others \cite{5,32,66} were unable to detect any mitogenetic effect.

In view of the contradictory results obtained with biological detectors, some workers \cite{5,65} introduced physical detectors such as the photographic plate and the UV-sensitive Geiger tube in order to detect the UV photon emissions. Unfortunately, the results using physical detectors were as variable as those obtained with biological detectors. In the 1930s, the careful but negative experiments of Hollaender and Claus \cite{31}, Gray and Ouellet \cite{25}, Lorenz \cite{44} and others challenged the existence of all the mitogenic phenomena and work subsequently ceased in Western countries. Some early reviews \cite{5,30,63} have described the early mitogenetic work in more detail. Despite this, work \cite{21,26,41} continued in East European countries with surprisingly little acknowledgement of the