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PRODUCTION OF CHARGED PARTICLES ON LASER IRRADIATION OF BIOLOGICAL SYSTEMS

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I. Introduction

High speed photography has indicated that when biological systems are exposed to laser radiation in the twenty joule range and above, a plume of volatilized material is ejected from the target. Techniques have been developed in this laboratory whereby charged particles with energies up to one electron-volt have been detected within the plume.

II. Magnetic Field Detection

A charged particle moving in a magnetic field experiences a force at right angles to both the direction of motion and to the direction of the magnetic field. This force is proportional to the magnetic field strength, to the electric charge strength of the particle, and to the particle speed. Since the magnetic force always acts at right angles to the particle motion, the resultant particle trajectory will be circular when the magnetic field is uniform, and when no external perturbation such as an electric or gravitational field is present. The circular trajectories are traversed either clockwise or counter-clockwise according to the sign of the particle charge (Figure 1).

If a charged particle enters a magnetic field at right angles to the field, the resulting circular trajectory will lie in a plane. If the particle enters a magnetic field obliquely, the circular trajectory becomes a circular spiral of constant pitch.

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When a charged particle moves in an inhomogeneous magnetic field, simple circular trajectories no longer exist. Figure 2 illustrates the trajectories of both negatively and positively charged particles initially moving at right angles to a spatially non-uniform magnetic field. As can be seen from the diagram, the effect of an inhomogeneous magnetic field is to produce a drift of the center of curvature of the particle trajectory.

Studies have been carried out in this laboratory where high speed photographs (8,000 - 10,000 frames per second) were taken of the motion of laser plumes moving through an inhomogeneous magnetic field on laser irradiation in the thirty joule range focused on the abdomen of black mice. Spiral plume macroscopic motion and confinement of the luminous part of the plume to a relatively small (1 cm^3) volume was observed (Figure 3) in agreement with the average effect of many charged particles moving in an inhomogeneous magnetic field (field strengths 0 - 300 gauss, field gradients of the order of 200 gauss/cm.). Comparison with plumes ejected from the abdomens of black mice on laser irradiation by a focused beam in the thirty joule range in the presence of zero magnetic field showed rapid dissipation of the plume over a large volume and no spiral trajectories (Figure 4). Some variation in trajectory path was observed during these studies. The laser unit employed was a Maser Optics Model 3100 incorporating a 6.5 X 0.375 inch ruby rod and an E.G. & G. FX 47-A flash tube.

Uncharged particles are unaffected by a magnetic field. Therefore, the presence of spiral plume trajectories and plume confinement in an inhomogeneous magnetic field indicates that the luminous plume ejected from biological systems contains a high density of charged particles. Plume visibility persists beyond the laser pulse and flash tube discharge duration. Visibility of the plume beyond the laser pulse duration can be due to illumination by

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radiation from the heated irradiation site on the mouse. This is probably not the mechanism of prolonged plume illumination since the target luminosity disappears much more rapidly than the plume luminosity as judged by high speed photography. Visibility of the plume can be due to self luminosity of the plume. Self luminosity must be due to re-radiation either from an excited state to ground state transition or due to recombination radiation. These modes of radiation occur in a plasma. High speed photography in conjunction with optical filters has shown that some constituents of the plume radiation are in the visible region, and consequently in the electron volt region. Therefore, some of the radiation observed must be due to recombination radiation. Consequently, some of the plume particles observed which are visible must be charged. It is possible that this ionization occurs just after the particle itself is ejected — the particle then being further heated due to continued absorption of laser radiation following ejection from the target. Another possible mechanism for creating charged particles is through inelastic collisions between free electrons and uncharged atoms present in the plume. The presence of charged plume particles was substantiated by the studies outlined in the following section.

III. Probe Detection

A small, metallic, conducting probe, suchaas a length of copper wire, is considered to a first approximation, to be "composed" of electrons free to move about within the boundaries of the wire. When a small conducting probe is enveloped by a moving cloud of both positively and negatively charged particles, the free negative charges on the probe surface will move so as to produce a probe voltage change if the cloud has a net positive or negative

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charge or if there is a tendency for positive and negative charges to group together within the cloud.

In the studies carried out in this laboratory, copper probes initially held at ground potential were positioned near the path of the plume. If a net charge were present within the plume a voltage would be induced in the probe. Direct laser irradiation of the probe produced no detectable probe voltage change. During experiments on charged plume particles, precautions were also taken to avoid direct irradiation of the probes. Probe voltage changes were detected when copper probes were placed near the path of the plume ejected from various physical and biological targets on irradiation in the 20 joule range. By positioning two probes a measured distance apart along the approximate plume path a voltage difference was detected between the two probes as a function of time. This data verified the presence of charged plume particles and allowed an estimate to be made of the average velocity at which the plume expands. Charged particle velocities as high as 10^4 cm./sec. were detected.

Other studies were carried out using streak photography. The plume particle velocities measured with this technique were in agreement with the velocities obtained by probe measurements at some distance from the animal. However, streak photography indicated that pbservable initial plume particle velocities near the animal surface were at least five times greater than those velocities measured by probes placed at some distance from the irradiated animal surface. An analytic model of the plume indicates that many electron velocities within the plume will exceed the velocity of mass plume motion by at least an order of magnitude (greater than 10^5 cm./sec.). Because the electron mass is extremely small, these velocities represent very low electron energies.

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IV. Free Radical Detection*

Electron spin resonance measurements following irradiation of black mouse skin and homolysin preparations indicated with high probability that free radicals are produced in these biological materials on laser irradiation. Irradiated skin of white mice and collagenase gave no signal.

* Carried out in collaboration with Dr. V.E. Derr, The Martin Company, Orlando, Florida.

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V. Summary

1. Magnetic fields, probe measurements and electron spin resonance studies indicated with high probability that charged particles are produced during laser irradiation, and that charged particles are present in the plume.

2. The "C" type magnet used was positioned with one pole face in front of the animal surface but 2 cm. or more laterally distant from the incident laser beam. The field strength of the magnet varied from a maximum of 300 gauss near the pole face to a much lower strength at a distance from the pole face. A high magnetic field gradient was therefore present in the region of the plume. The ruby laser energy used in these studies was of the order of 30 joules focused to a spot size in the millimeter range somewhat below the skin surface. The exact position of the focal point could not be determined due to normal movement of the animal, including respiratory excursions.

Acknowledgments

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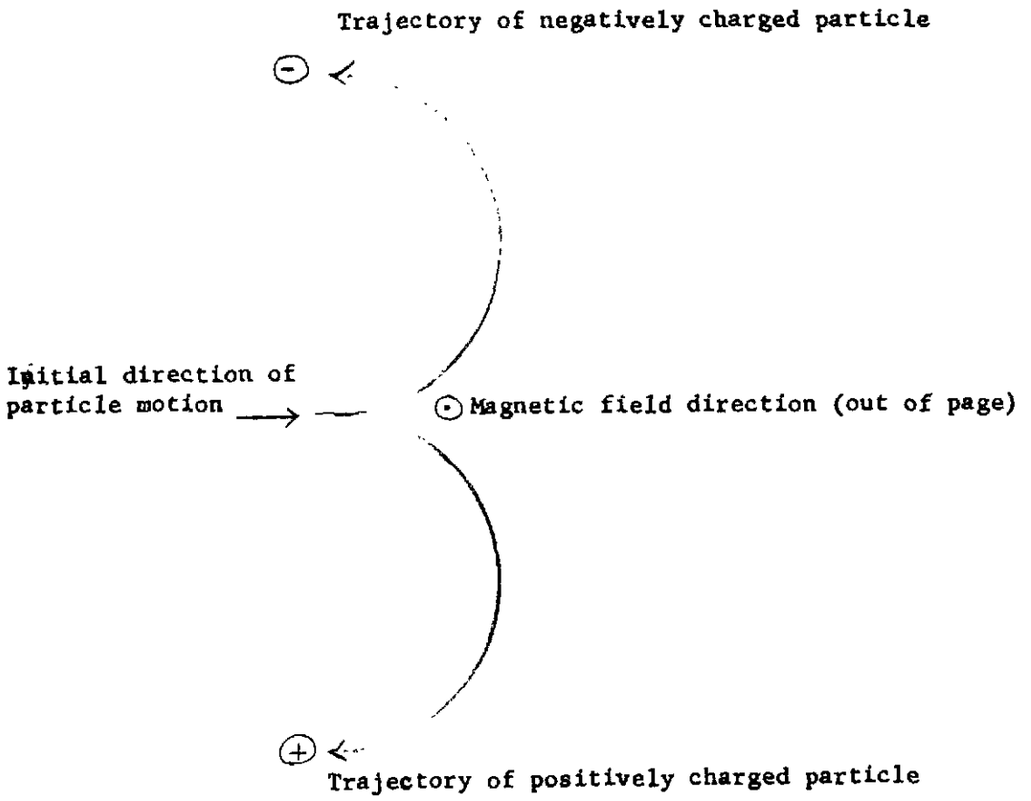

Figure 1.

Trajectory of charged particles in a homogeneous magnetic field.

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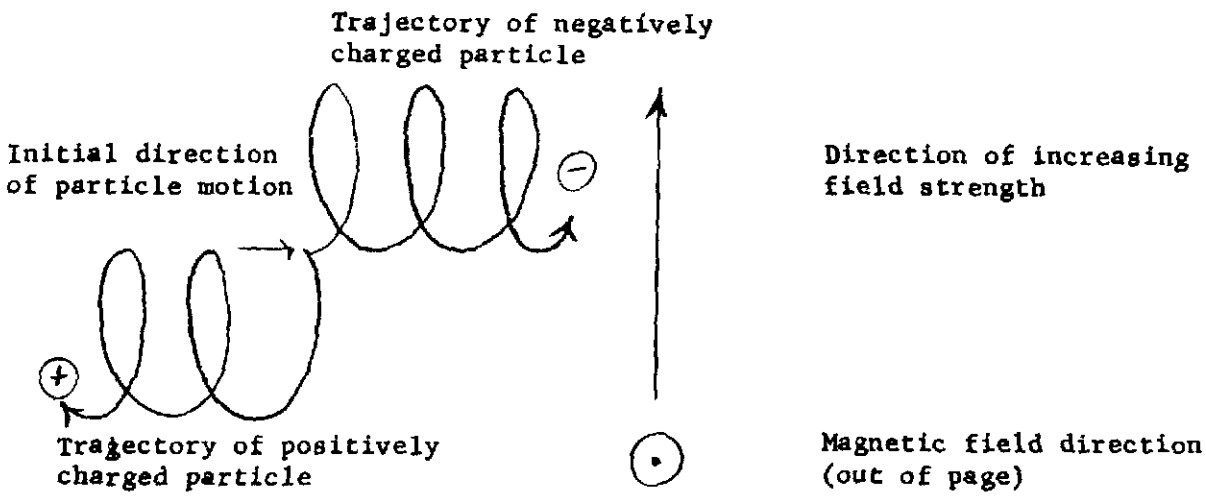

Figure 2.

Trajectory of charged particles in an inhomogeneous magnetic field.

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Figure 3

Spiral Plume trajectories in an inhomogeneous magnetic field.

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Figure 4

Unperturbed plume trajectories in zero magnetic field.

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