PHOTOELECTRIC PLETHYSMOGRAPHY USING FIBER OPTICS FOR APPLICATION IN THERMAL PHYSIOLOGY

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FOREWORD

The experimental work reported herein was conducted in the Department of Physiology, Saint Louis University School of Medicine, Saint Louis, Missouri, in partial fulfillment of Contract AF 33(657)-11551, administered by the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. Mr. John F. Hall, Jr., Chief, Biothermal Branch, Physiology Division, served as the contract monitor for the Biomedical Laboratory. The work was performed under Project No. 7164, "Biomedical Criteria for Aerospace Flight," Task No. 716409, "Human Thermal Stress." Alrick B. Hertzman, Director of the Department of Physiology, was the Principal Investigator of this research project. The development of the device as described in this report occurred during the period, May 1963 through September 1964.

Part of the cost of this research was covered by grants H-4939 and HE-07070 from the United States Public Health Service.

This technical report has been reviewed and is approved.

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ABSTRACT

Several designs of photoelectric plethysmographs utilizing fiber optics are described. One arrangement is used for studies on the cutaneous circulation. A modification of this design was applied successfully to the oral mucosa in climate chamber experiments. With a light wire substituted for the photocell, interference filters and multiplier phototubes may be combined for spectrophotometric recording. This arrangement is particularly useful for following changes in blood content of the illuminated tissue during changes in ambient temperature.

INTRODUCTION

Interest in this laboratory in extending observations of vascular responses to various ambient temperatures and of combinations of external heat with various levels of metabolic heat production led to efforts in re-designing the photoelectric plethysmograph. Lightness in weight, increased freedom from movement artifacts, removal of the light source from contact with the assembly in order to eliminate local heating effects from the light were principal objectives in design. Selection of fiber optics proved effective in serving these purposes. The success of Giddon (1) and of Heck and Hall (2) in using fiber optics in applying the technic of photoelectric plethysmography to the gingival circulation (1) and the brain and ear (2) encouraged the development of the design described in this report.

DESIGN

Figure 1, drawn to scale, shows two views of the photoelectric unit which was fabricated to receive photocell, light wire, mirror and thermocouple. The bottom part of this figure is a transverse section at an angle of 90°. It shows the positions of the holes drilled to receive the photocell, light wire and thermocouple.

In the top part of figure 1, the assembly is seen from the bottom or skin surface with photocell, light wire, mirror and thermocouple in place. The Clairex photocell CL903 having a vertical height of about 4 mm was used. The light wire had a diameter of 4.76 mm. The mirror was the end surface of a rod of stainless steel cut at an angle of 45° and highly polished. A slot in the end of this rod permitted adjustment of the reflected light beam so that it struck the skin close to the photocell's contact with the skin. The end of the light wire was very close to this mirror.

This photoelectric arrangement was an integral part of a larger ring of plastic which served as a mount. Four feet cemented on this ring limited the pressure of contact of the photoelectric unit with the skin. Slots in this ring provided reception for various belts or other devices for holding the device against the skin. In applications to the digits, it is convenient not to include the plastic ring support during the construction of this unit.

A variation in this design for application to the cheek mucosa is shown in figure 2. A groove was cut into the plastic unit to permit suction of the mucosa into the groove thus keeping the unit in constant contact with the mucosa. Other features of this device are indicated in the legend of figure 2. This adaptation of photoelectric photometry has been used successfully in climate chamber experiments over periods of 4 to 6 hours.

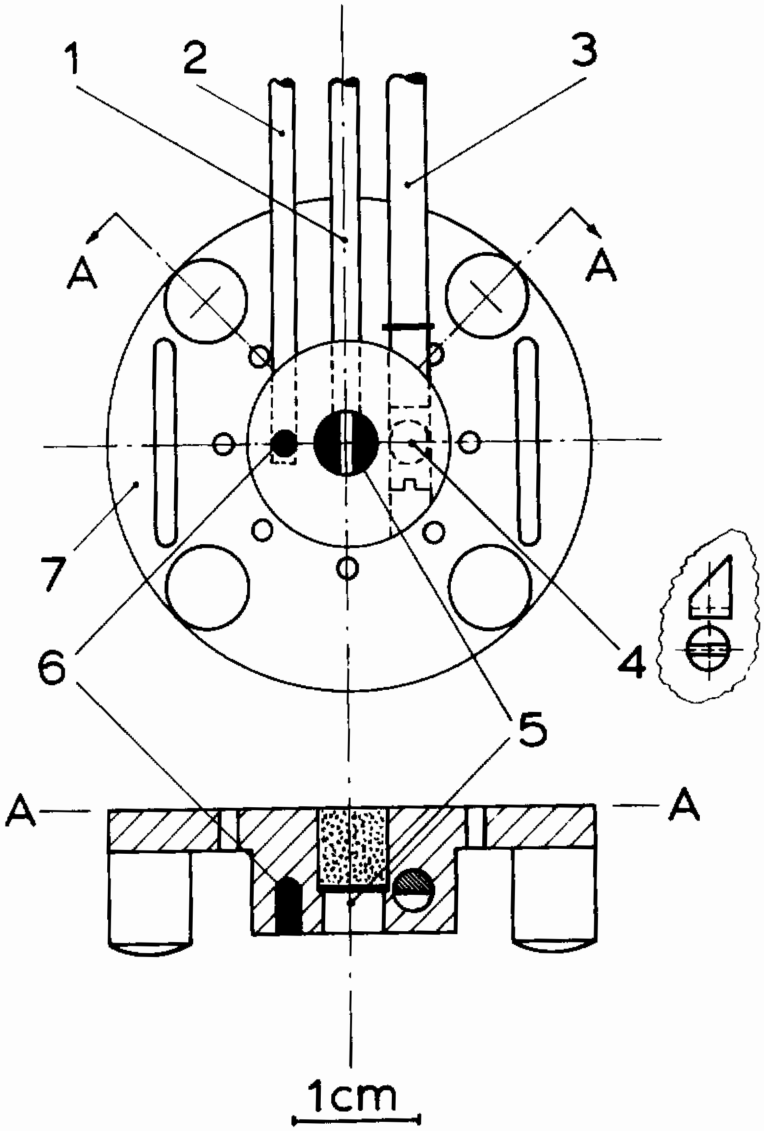

Figure 1. Cutaneous photoelectric plethysmograph with fiber optics. Top section, seen from skin surface: 1 - photocell lead, 2 - thermocouple lead, 3 - light wire, 4 - mirror (shown also beside number 4), 5 - photocell, 6 - thermocouple, 7 - plastic ring support. Lower section, seen at 90° from the top figure.

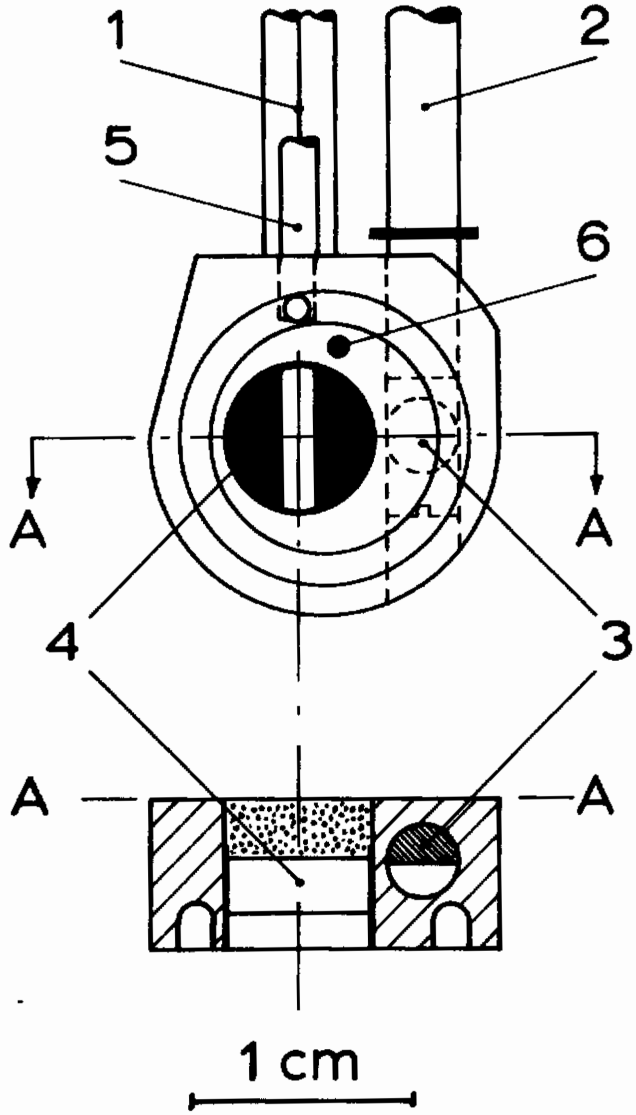

Figure 2. Photoelectric plethysmograph for the oral mucosa, using fiber optics. Top section, seen from the mucosal surface: 1 - photocell lead, 2 - light wire, 3 - stainless steel mirror, 4 - photocell, 5 - tube connecting with groove to apply suction to the mucosa, 6 - thermocouple junction. Lower section, seen at 90° to the top section.

Figure 3 shows the assembly of a convenient light source. An ordinary pencil flashlight bulb was used because of its condensing lens. A second condensing lens cut from the end of such a bulb was mounted between the light wire and bulb. Since the optics of this system are inaccurate, the crude sliding adjustments for optical alignment could be backed in place by the screws shown in the figure.

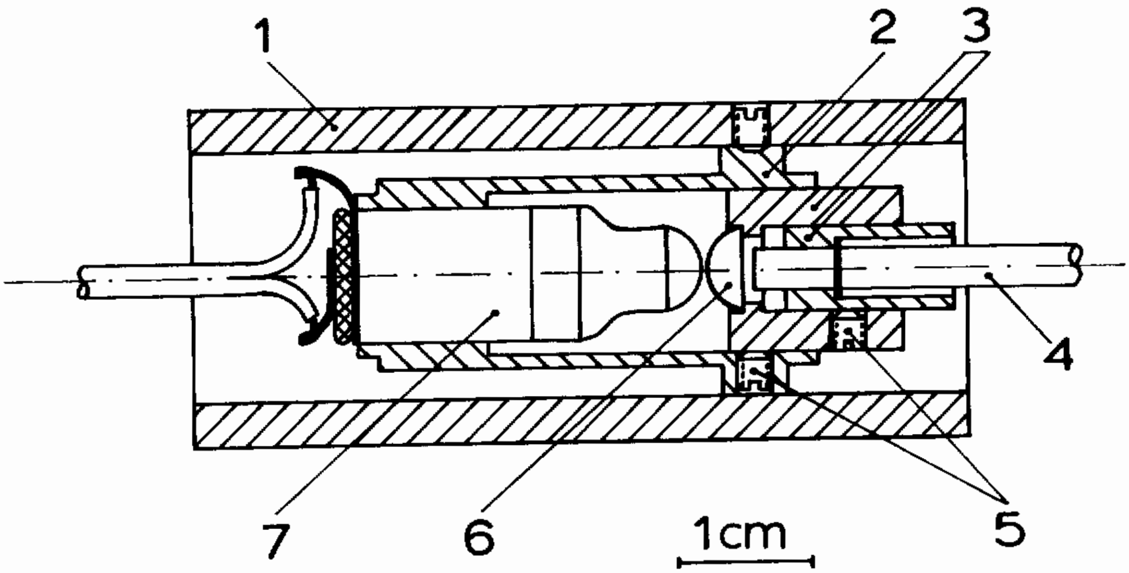

Figure 3. Light source, using pencil flash light bulb. 1 - plastic housing, 2 and 3 - brass housing, 4 - light wire, 5 - set screws, 6 - lens cut from light bulb, 7 - light bulb and mount.

In applications of the photoelectric unit to the skin surface, the light assembly could be taped on the same body part or mounted in a clamp attached to the cot or chair on which the subject rested. Taping to the body was necessary if considerable movement was to be allowed. Increased length of the light wire permitted greater freedom of movement and of application but also slightly reduced the intensity of the skin's illumination.

A modification of this design permits elimination of the effects of temperature on the photoelectric sensor. A second light wire replaces the photocell, conducting the light to a phototube mounted in a suitable housing. The light wire may be inserted vertically in the plastic disc instead of the photocell or horizontally and parallel to the first light wire, using a second mirror to reflect light into the light wire. Since phototubes and multiplier phototubes have negligible temperature coefficients, this arrangement is particularly useful in climate chamber experiments when one desires information on changes in the opacity of the skin. Insertion of interference filters in the light path to a multiplier phototube having a cathode response of S-1 permits spectrophotometry of the illuminated tissue.

The circuit for the power supply of the light bulb is shown in figure 4. A highly regulated stable supply is necessary for prolonged continuous observations. Drift in the output of the photocell bridge was not detectable with this power supply which was mounted on the same panel as the bridge circuit for the photocell. The components of the bridge are shown in the lower section of figure 4.

Since the method of calibrating the photometric recordings usually employs the deflections resulting from turning off the light, the off-on switch in the power supply output connects in the "off" position with a resistance about equal to that of the light bulb. This arrangement largely eliminates loading and unloading of the power supply.

The thermocouple inserted alongside the photocell demonstrated that there was no heating of the skin under the photometer by the illumination. This thermocouple also provided for measuring the skin temperature in the same area where the photometric measurements were obtained.

Estimations of the amplitudes of the forearm's cutaneous opacity pulses recorded by this photometric system agreed with those obtained from simultaneous recordings made by an earlier design (3). This was true for the heated as well as for the comfortable subject. The principal advantages of this new design appear to be mechanical and the opportunity of combining conveniently interference filters and multiplier phototubes when special spectrophotometric studies are desired. Fiber optics permit use of the principle of the periscope in adapting photoelectric plethysmography to tissues below the body surface.

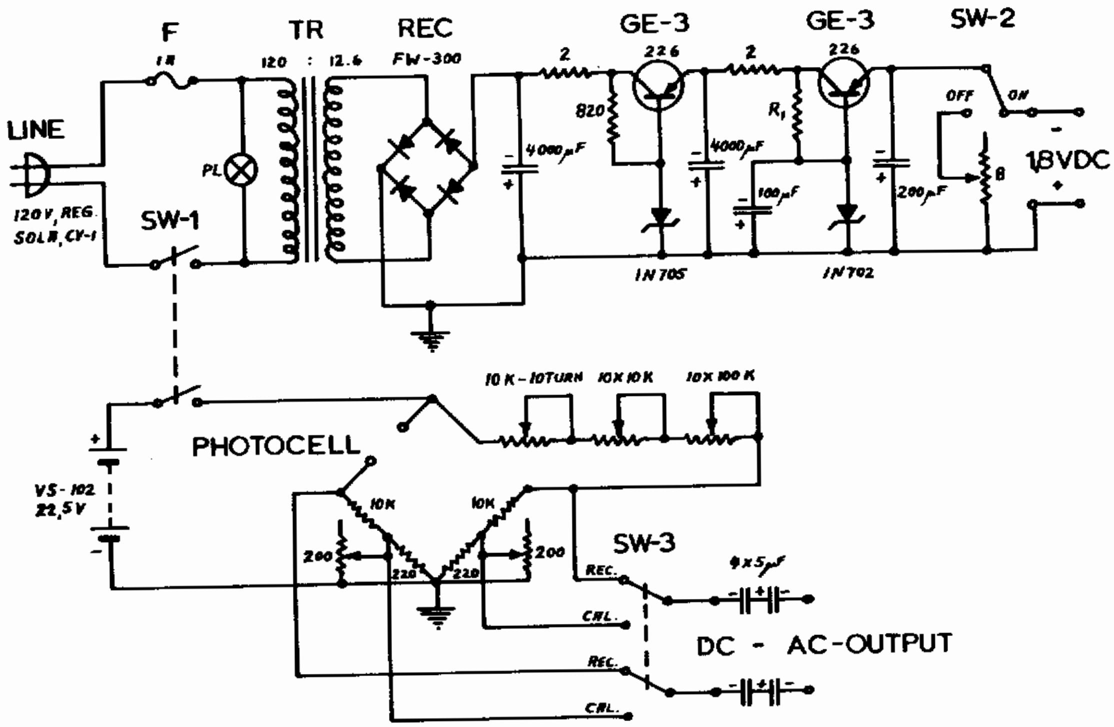

Figure 4. Regulated power supply for light bulb and photocell bridge circuit. The off-on switch, SW-2, connects with either the light bulb or a shunting resistance, 8, to permit turning the light on or off as a calibrating procedure. The switch, SW-3, in the bridge circuit drops the output signal to the recorder by a fixed fraction when turned to the calibrating (cal) position. This procedure is used in calibrating the opacity pulses in per cent of photoelectric current.

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Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* St. Louis University School of Medicine, Department of Physiology St. Louis, Missouri 63166	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

PHOTOELECTRIC PLETHYSMOGRAPHY USING FIBER OPTICS FOR APPLICATION IN THERMAL PHYSIOLOGY

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final report May 1963 - September 1964

5. AUTHOR(S) *(Last name, first name, initial)*

Hertzmann, Alrick B.
Flath, Franz

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
April 1966	12	3

8a. CONTRACT OR GRANT NO. AF 33(657)-11551	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 7164	
c. Task No. 716409	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	AMRL-TR-66-31

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	Aerospace Medical Research Laboratories Aerospace Medical Division, Air Force Systems Command, Wright-Patterson AFB, Ohio

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DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Medical technology Fiber optics Cutaneous circulation Photoelectric plethysmography						

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