Output of Electrical Energy by Frog-Skin

IF a piece of frog-skin, mounted with glucose Ringer solution on both sides, is connected in series through two calomel electrodes with a micro-ammeter, a current may be observed to flow through the circuit for many hours. With a piece of skin 1.6 cm.² in area in a circuit of total resistance 1,500 ohms the current is $20\text{--}30 \times 10^{-6}$ amperes during 12 hours after setting up.

Between 0° C. and 30° C. the resistance of the skin falls steadily, the potential rises to a maximum at about 20° C. and then falls off, and the current rises to a maximum at about 25° C. before decreasing. The output of electrical energy by the skin can be calculated as equivalent to the Joule heat developed in the circuit. This was found for four different skins to lie between 5 and 9×10^{-3} calories per minute per gram dry weight of ventral skin at 20° C. It has been shown^{1,2,3} that when the ionic composition of the solution is constant the frog-skin potential is maintained by oxidation processes. It is of interest, therefore, to see what fraction of the energy released by oxidation may appear as electrical energy. The respiratory quotient of the skin of *Rana temporaria* is 0.97⁴. The average oxygen consumption of frog-skin⁵ was found to be 20×10^{-3} c.c. oxygen per minute per gram dry weight at 20° C. (other values are summarised by Adolph⁶). Assuming that molecules of $(C_6H_{12}O_6)_n$ are burnt and taking the heat of combustion per gram as 680,000 calories, it will be found that the energy released by oxidation processes is on the average 100×10^{-3} calories per minute per gram dry weight at 20° C. The electrical energy output calculated above is 5–10 per cent of this value.

The temperature coefficient of the electrical energy output for a rise of 10° C. was determined for three skins and compared with the average Q_{10} for respiration for four skins.

	Q_{10} Electrical Energy			Q_{10} Energy from Combustion.
0° C.–10° C.	2.85	1.99	3.90	3.6
10° C.–20° C.	1.4	1.44	1.41	2.0
20° C.–30° C.	—	—	—	1.9

The power output is a maximum at 24° C. for the electrical process and at 38° C. for the respiratory processes of the skin. Lund and Moorman⁶ have found that values of Q_{10} for potential and oxygen consumption of the skin of *R. pipiens* between 16.4° C. and 26.4° C. are 2.14 and 2.01 respectively. (In my work Q_{10} for the potential in this interval is near unity.) They adduce this approximate equality in support of a theory of the skin potential based on "the flux equilibrium of the oxidation-reduction systems" in the cells of the skin. Since, however, the frog-skin does not behave as a reversible galvanic cell, the potential cannot be related directly to the energy released by oxygen consumption except on the lines indicated above.

There are also objections to the interpretation of the skin potential, which is measured between reversible calomel electrodes, in terms of oxidation-reduction potentials which can only be measured with the aid of an inert metal electrode to act as an electron donor or acceptor⁷. The skin potential, like the injury potential of crab's nerve⁷, depends on oxygen consumption and also on the nature and

concentration of the electrolytes present⁸. With these two factors in mind, further work is in progress in conjunction with Dr. R. J. Pumphrey, on the nature of the frog-skin potential.

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¹ Lund, *J. Exp. Zool.*, **51**, 265, 291, 327; 1928.

² Francis and Pumphrey, *J. Exp. Biol.* In press.

³ Francis, *J. Exp. Biol.* In press.

⁴ Bornstein and Klee, *Arch. exp. Zellforsch.*, **3**, 395; 1927.

⁵ Adolph, *J. Exp. Zool.*, **53**, 313; 1929.

⁶ Lund and Moorman, *J. Exp. Zool.*, **60**, 249; 1931.

⁷ Hill, *NATURE*, **131**, 501; 1933.

⁸ Uhlenbruck, *Z. Biol.*, **82**, 225; 1924.

The Astronomical Radiative Stability

ASTRONOMERS are doubtless not unaware of the enormous radiative uniformity that is demanded by the permanence of organic life on the earth. If the temperature at the earth's surface were altered even for a single season from its actual value about, say, 27° C. or 300° K., by 50° in excess or defect, all terrestrial organic life would be blotted out never to return. This would happen if even only once in the hundred million years demanded for terrestrial organic evolution the effective temperature of the solar radiating surface changed from the present mean value 6,000° K. by 1,000° in excess or defect, if it were a matter of steady state, while during the time of this change the stream of radiation incident on the earth would be altered in a proportion much greater. On current theories the difference between the top and bottom of the radiating solar atmosphere would be great in comparison with this figure, and lower down vast temperatures are soon reached. This shows how extremely steady the balance must be, and how slight the solar evolution must have been even in that vast time. As one result, the sunspot disturbances, even though they occupy only a very small part of the area of the solar disc, would have to be purely superficial phenomena. The output of radiation is very steady, as from a steady interior; yet the heavens are full of variable stars. Perhaps these considerations were remotely in view when long ago Whewell and Brewster were discussing the plurality of worlds, and Huxley championed the geologists against Kelvin.

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The Combustion Problem of Internal Ballistics

IN a recent paper on the combustion problem of internal ballistics¹, we have attributed jointly to Love and Pidduck² a statement as to the importance of including both temperature and pressure in the rate of burning law for colloidal propellants. Their paper was published in two parts, and the statement in question was made in Part 2, which was entirely the work of Dr. Pidduck. Our reference, in consequence, was misleading, and we desire to correct the error.

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¹ *Phil. Mag.*, **7**, 15, 529; 1933.

² *Phil. Trans.*, A, **222**, 599; 1922.