

Theoretical Model for Bio-Photon Energy Harvesting and Electrical Energy Storage Using Organic Photochemical Systems

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Abstract

Biophotons are ultra-weak light emissions generated by living organisms as a result of metabolic and oxidative biochemical reactions. These emissions, although extremely low in intensity, represent a continuous and naturally occurring source of electromagnetic energy. In this theoretical study, a conceptual model is proposed for the absorption of biophoton energy using organic photoactive materials and its conversion into electrical energy followed by efficient storage. The model employs porphyrin-based absorbers, organic semiconductors, graphene-based charge transport layers, and bio-electrochemical interfaces to facilitate electron transfer. The harvested micro-current is theoretically stored using graphene-enhanced supercapacitors or bio-inspired redox storage systems. Mathematical expressions governing photon absorption, charge generation, electrical output, and storage efficiency are developed. Although the system is not intended for large-scale power generation, it demonstrates potential applicability in self-powered biosensors, biomedical devices, and future nano-bioelectronic systems.

Keywords: Biophotons, Energy harvesting, Organic semiconductors, Photochemistry, Graphene, Supercapacitors, Bioelectrochemistry

1. Introduction

Energy harvesting from unconventional and biological sources has emerged as an important area of scientific research due to increasing demand for sustainable and self-powered systems. Among such sources, biophotons—ultra-weak photons emitted by living cells—have attracted interest in biophysics and bioelectrochemistry. Biophoton emission arises from electronically excited molecular species generated during metabolic reactions, oxidative stress, and electron transfer processes in cells.

While biophotons are well-documented experimentally, their direct utilization as an energy source remains largely unexplored. This paper proposes a purely theoretical framework for capturing biophoton emissions and converting them into usable electrical energy using established principles of photochemistry, electrochemistry, and materials science. The proposed system does not claim high power output but focuses on feasibility at the micro- and nano-energy scale.

2. Scientific Basis of Biophoton Emission

Biophoton emission originates from excited biomolecules such as flavins, porphyrins, and reactive oxygen species formed during biochemical reactions. These excited species relax to lower energy states by emitting photons primarily in the ultraviolet to visible region (400–700 nm).

The energy of an individual biophoton is given by:

$$E = h\nu = \frac{hc}{\lambda}$$

where: - h is Planck's constant, - ν is the frequency of radiation, - λ is the wavelength of emitted light. Although the photon flux is extremely low, continuous emission makes theoretical harvesting possible using high-sensitivity materials.

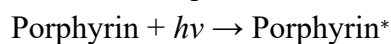
3. Proposed Theoretical Model

3.1 Biophoton Absorption Layer

The first stage of the system involves absorption of biophotons using organic photoactive molecules. Porphyrins and conjugated polymers are proposed due to their extended π -electron systems and low band gaps, which enable absorption of weak visible light.

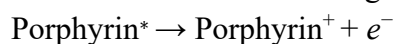
Proposed materials: - Synthetic porphyrins and metalloporphyrins - Conducting polymers such as PEDOT:PSS and P3HT

The absorbed photon excites the molecule to a higher electronic state:



3.2 Charge Separation and Transport

The excited molecule undergoes photoinduced electron transfer, generating free charge carriers:



Graphene or carbon nanotube layers are introduced to facilitate rapid electron transport and reduce recombination losses due to their high electrical conductivity and electron mobility.

3.3 Bio-Electrochemical Interface

To bridge the biological and electronic domains, redox mediators such as quinones or flavin derivatives are incorporated. These mediators accept electrons from the photoactive layer and transfer them to the electrode surface, generating a measurable electrical current.

The resulting current is expressed as:

$$I = N \cdot e \cdot \eta_c$$

where: - N is the number of electrons generated per second, - e is the elementary charge, - η_c is the charge collection efficiency.

4. Energy Storage Mechanism

4.1 Supercapacitor-Based Storage

Due to the low magnitude of generated current, supercapacitors are proposed for energy storage.

Graphene-based supercapacitors offer high surface area and fast charge–discharge capability.

The stored energy is given by:

$$E = \frac{1}{2}CV^2$$

where: - C is capacitance, - V is operating voltage.

4.2 Bio-Inspired Redox Storage

Alternatively, energy may be stored in reversible redox couples such as quinone/hydroquinone systems, mimicking biological energy storage pathways similar to NADH/NAD⁺ cycles.

5. Overall Energy Conversion Efficiency

The total harvested energy can be expressed as:

$$E_{total} = N \cdot hv \cdot \eta_a \cdot \eta_c \cdot \eta_s$$

where: - η_a is absorption efficiency, - η_c is charge conversion efficiency, - η_s is storage efficiency.

6. Limitations of the Model

- Extremely low photon emission intensity
- High susceptibility to thermal and electronic noise
- Low overall conversion efficiency
- Requirement of advanced nano-materials
- Currently impractical for macroscopic power generation

7. Potential Applications

- Self-powered biosensors
- Biomedical implants
- Low-energy wearable devices
- Bioelectronic monitoring systems
- Fundamental research in bioenergy conversion

8. Future Scope

Future research may focus on enhancing photon absorption efficiency using quantum dots, improving charge separation via nanostructured materials, and integrating artificial intelligence for material optimization. Hybrid bio-electronic systems may further improve feasibility.

9. Conclusion

A comprehensive theoretical framework for biophoton energy harvesting has been proposed based on established principles of chemistry and materials science. While practical implementation remains challenging, the model provides a scientifically sound foundation for future exploration of bio-inspired energy systems.

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