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P5_5 Boiling the Ocean

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Abstract

We approximate the energy required to bring the entire of the Earth's oceans to boiling without a change of state. The energy is calculated to be $5.33 \times 10^{26} J$. We then put into perspective how much energy this is in the form of nuclear weapons, meteorite impacts, mass-energy conversion and 9V household batteries.

Introduction

Approximately 71% of the Earth is covered by salt water. Approximately 97% of the Earth's water resides in the oceans and seas [1]. This large body of fluid has a high heat capacity compared to most common liquids which helps to regulate the temperature of the Earth [2]. To investigate the energetic capacity of the ocean we calculate the heat required to instantaneously bring the entire ocean to boiling temperature without a change of state. We then compare this value to various energy sources.

Volume and Mass of the Oceans

The volume of Earth's oceans is listed at an average value of 1.35 billion cubic kilometres [3]. This is $1.35 \times 10^{18}\ m^3$.
Mass is given by,

$$m = \rho V, \qquad (1)$$

where, ρ is the density and V is the volume of the ocean. The density of seawater changes slightly over the depth of the ocean. At sea level saltwater has a density of $1{,}020\ kg \cdot m^{-3}$ [4]. $11 km$ deeper in the deepest trenches of Earth's oceans, the density is closer to $1{,}050\ kg \cdot m^{-3}$. We assume an average density $\rho = 1{,}030\ kg \cdot m^{-3}$. Equation 1 then gives a mass of $1.391 \times 10^{21} kg$.

Boiling the Ocean

The surface temperature of the ocean can range heavily between the tropics and poles. However, in reality the surface makes up very little of the ocean's volume.

Ocean temperatures are steadier below $1000m$ slowly decreasing from around 4°C to around -2°C in the deepest coldest parts [5].

As the average depth of the ocean is approximately $3682m$ [3], we assume an average temperature of around 3°C.
The specific heat of sea water is approximately $3930\, Jkg^{-1}K^{-1}$ [2]. On average the boiling point of seawater is only very slightly higher than freshwater at 100.5°C. [4]

The change of heat energy of a material with temperature is given by

$$\Delta Q = cm\Delta T, \qquad (2)$$

where ΔQ is the required energy to raise the mass m of material with specific heat capacity c by ΔT degrees. This does not take into account a change of state as we are only interested in the storage capacity of liquid water.

Equation 2 gives a total energy required of $5.33 \times 10^{26} J$ required to boil the entire ocean.

Comparison to Energy from Nuclear Weapons

Nuclear weapons are currently the most energetic created by mankind. The energy of resulting nuclear explosions is commonly expressed in units of tons of TNT, each with a value of $4.184 GJ$.
The energy equivalent to boil the entire ocean is therefore 1.27×10^{17} tons of TNT. The

total global nuclear inventory is approximately $17{,}300$ warheads estimated at 5 gigatons of TNT destructive power. [6]

This is much smaller than the calculated energy to boil the ocean. We calculate that it would take approximately 25 million global nuclear arsenals detonating simultaneously to release this much energy.

Meteorite Impact

Another notable release of energy is the Chicxulub asteroid impact which is estimated at 100 teratons of TNT [7]. This would give the energy equivalent of 1270 Chicxulub asteroids required to boil the ocean.

Mass energy

The most direct conversion from matter to energy is the annihilation of matter with antimatter. This can be calculated using,

$$E = mc^2, \qquad (3)$$

where the theoretical maximum for energy extraction from $1kg$ of matter is c^2 Joules, ~ 90 petajoules per kg.

From this it can be calculated that $5.9 \times 10^9\, kg$ of mass would need to be directly transformed into energy to boil the entire ocean.

9V batteries

The "Energizer" 552 $9V$ battery has around $600mAh$ of energy per volt when discharged at a constant current of $25mA$ [8]. The average power of this discharge is voltage multiplied by current,

$$P_{avg} = IV, \qquad (4)$$

therefore multiplying by a discharge time t,

$$P_{avg}t = E = ItV, \qquad (5)$$

one can calculate the energy associated with the discharge. Assuming the battery remains at $9V$ over a discharge time of 24 hours the energy extracted is $19.44kJ$.

This means approximately 2.74×10^{22} batteries would be required to meet the energy to boil the ocean.

Conclusion

The energy required to boil the ocean is approximately $5.33 \times 10^{26} J$, far beyond that which humans can readily produce. Comparing this to various methods of production it can easily be seen that unleashing this much energy at once would be catastrophic and probably result in the end of human life on Earth. Further problems including changes in temperature with sea ice could be investigated further.

References

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