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## The Frog Prince Transformation

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**Abstract**
Transformations are a common trope in fairy tales and many other media. Although they are often a core element to the story and aid in plot progression, the details about physical viabilities are often neglected. The Frog Prince (or Iron Henry) is one such example; the story features a frog turning into a prince with a significantly larger mass. While this may appear to contradict the laws of mass and energy conservation, on closer inspection, such a transformation is theoretically possible.

**Introduction**

The frog prince is a well-known fairy tale by the German authors Brothers Grimm. The climax of the story involves the transformation of the frog into a prince through a kiss by a spoiled princess. Since the transformation from a frog to a human comes with a large change in mass, this paper aims to investigate the possibility of such a feat with regards to the law of energy and mass conservation.

**Frog to Prince**

It is apparent that the mass of a frog is less than the mass of fully grown man. Considering the largest known frog species, the goliath frog (*Conraua goliath*) may grow up to 3.3 kilograms[1] , and that the average mass of a male human adult is 88.7kg[2], the difference in mass is:

$$88.7kg - 3.3kg = 85.4kg.$$

Assuming an instantaneous transformation and conservation of mass, the acquisition of 85.4kg has to be taken in as energy from the environment. Since mass in form of atoms and molecules cannot be readily "absorbed" by the frog and converted to organic matter, the energy equivalent is chosen instead.

Einstein's formula for mass-energy equivalence shows the relation between (rest) mass and energy[3]:

$$E = mc^2$$

Here, $E$ is the energy, $m$ is mass and $c$ is the speed of light. Using this equation, the mass can be converted into an equivalent energy:

$$E = (85.4\ kg)(2.998 \times 10^8\ m\ s^{-1})^2 = 7.69 \times 10^{18} J$$

Putting 7.69 exajoules in perspective, the United States of America consumes 14 exajoules of electricity in 2009[4].

**Sources of the Energy**

In many animated adaptions of the Frog Prince (or Iron Henry), the transformation of the frog into the prince is facilitated by a glowing body and light reaching into the body from the surroundings. The most readily available energy from the surroundings is the kinetic energy of air surrounding the frog. A simple way of finding the kinetic energy is by assuming the air behaves as an ideal gas (no in intermolecular attractive forces and perfect elastic collisions) and using the average kinetic energy (per mole of gas) formula:

$$KE_{avg} = \frac{3}{2}RT$$

Here, $R$ is the universal gas constant and $T$ is the temperature [5]. We will set the temperature to 20°C (293.15K), a warm German (origin of the authors) spring day. The average kinetic energy per mole will be:

$$KE_{avg} = \frac{3}{2}(8.3145\ J\ mol^{-1}K^{-1})(293.15K) = 3656\ J\ mol^{-1}$$

In order to gain the amount of energy required for a successful transformation, $2.10 \times 10^{15}$ moles of gas are required. Since the molecular mass of air is $0.02897\ kg\ mol^{-1}$[6], the required mass is therefore:

$$2.1 \times 10^{15} mol \times 0.02897\ kg\ mol^{-1} = 6.08 \times 10^{13} kg$$

Considering that the total mean mass of the atmosphere is $5.15 \times 10^{18} kg$[7], the effect of the transformation would span an area of approximately $1.1 \times 10^{-5}$ times the Earth.

**Conclusion**

It is theoretically possible to gain enough energy for the transformation of a frog to a prince from the kinetic energy of air alone. However, extraction of such amount of energy is practically impossible for present science, as it would require extracting all kinetic energy from the air molecule. This would result in an environment of absolute zero temperature. While solar heating would slowly provide the air with energy again, the health of the prince/frog and any other person (princess) in the area cannot be assured. Considering that story was written and set in an age more than a hundred years ago, such a feat can truly only be achieved with magic.

**References**

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