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How hot is a hypersonic vampire?

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Abstract
In the light novel series *Monogatari*, the legendary vampire Kiss-Shot Acerola-Orion Heart-Under-Blade once travelled to Antarctica, wanting to see the aurora australis. To leave the continent, without a destination in mind, she jumped with such force such that the recoil threatened to destroy the landmass of Antarctica. Travelling at hypersonic speeds, and coincidently landing in an unknown Japanese lake caused the entire volume of water 'to disappear'. No process is completely efficient, and assuming this jump generated a great amount of heat, this paper finds that Kiss-Shot would have been hot enough to vaporise any inland volume of water in Japan.

Keywords: *Light Novel; Anime; Physics; Thermodynamics; Monogatari; Kiss-Shot Acerola-Orion Heart-Under-Blade*

Introduction
In Nisio Isin's *Monogatari* light novel series, as well as the unique Studio shaft adaptation, the protagonist Koyomi Araragi finds himself entangled in the lives of those affected by 怪異 – pronounced 'kai-i', which translates from Japanese to mean 'aberration' or 'strangeness'. These supernatural beings are based on myth, legend or tales from folklore. Dubbed 'the king of aberrations', vampires take an important role in the series, especially after Araragi is bitten by one prior to his third year of high school [1]. The perpetrator in question was the legendary vampire Kiss-Shot Acerola-Orion Heart-Under-Blade, a being powerful enough to 'make the Earth disappear' [2]. Now trapped in a weakened state, with the body of a young girl, she is never far from Araragi, often hiding in nearby shadows.

Figure 1 – Kiss-Shot's arrival into Japan, prior to landing. (Photo taken from [3]).

Over 400 years prior to the start of *Monogatari*, after her travels to Antarctica to see the aurora, she decided to jump to her next destination, somewhere close to the Pacific Ocean. Despite Kiss-Shot 'taking care not to', the recoil due to her jump 'threatened to destroy the Antarctic landmass' [2]. She coincidentally landed in a lake in Japan, 'making the lake disappear'. Nearby communities were suffering the effects of a long-lasting drought, and Kiss-Shot became revered as a God after inadvertently 'making it rain' [3]. This paper is a continuation of a previous work, *Antarctica's Kiss-Shot* [4], which explores the first half of this tale – the jump itself. This work explores the latter half of the tale; by using the energy calculated from that paper, a value of the heat generated by the jump will be inferred. This heat will have been assumed to have made the body of water she landed in fully evaporate – eventually leading to rain falling in the areas nearby.

Heat Flow
Assuming that vampiric biology follows a similar logic to other organisms, the production of mechanical energy using skeletal muscle is not perfectly efficient – with an upper bound of 35 % mechanical efficiency [5]. The total work done, W, by Kiss-shot's muscles during the jump is given by

$$W = Q_i + K + E \qquad (1)$$

where Q_i is generated heat, E is the energy transmitted into Antarctica, and K, the kinetic energy, $0.5mv^2$. Taken from the previous calculation in [4], the energy that was transmitted into the continent was $E = 303\ EJ$. Kiss-shots velocity, v, and kinetic energy, will be calculated using the Antarctica-Japan distance [6], and the travel time, Δt, 12 seconds – as this is the length of the animated transition [3], as assumed in a previous calculation [7].

$$v = \frac{d}{\Delta t} = \frac{1.3974 \times 10^7\ m}{12\ s} = 1.16 \times 10^6\ ms^{-1} \quad (2)$$

The speed of Mach 3382 may be a conservative estimate as Kiss-Shot at her zenith had the ability to travel at relativistic speeds; once travelling the Earth seven times in one second [8]. Assuming skeletal muscle efficiency of 35 % [5], Equation 1 can be rearranged to be in terms of mechanical energy to calculate Q_i, the waste heat generated by the jump. Kiss-Shot's temperature at the time of the jump, ΔT_i, can then also be calculated as shown in Equation 4. Despite being able to freely control her weight [9], Kiss-shot's mass in this case, m_s, will be assumed to be 66 kg, a reasonable estimate for an athletic female of her height [1, 10]. Her specific heat, c_s, will be taken to be that of the human body, 2980 $Jkg^{-1}K^{-1}$ [11], due to her previously human form [1].

$$Q_i = 0.65\frac{0.5mv^2 + E}{0.35} = 5.63 \times 10^{20}\ J \quad (3)$$

$$\Delta T_i = \frac{Q_i}{m_s c_s} = 2.86 \times 10^{15}\ K \quad (4)$$

A temperature of the order of 10^{15} Kelvin, seen microseconds after the Big Bang, should be hot enough to dissociate every atom in Kiss-Shot's body into its constituent quarks [12]. However, Kiss-Shot's ability to walk freely in the Sun, despite being disintegrated by its presence, is reflective of her regenerative abilities [2], and will be assumed to allow her body to remain in a steady state, despite her extreme temperature. Heat loss, ΔQ, due to conduction during transit can be described in Equation 5, where κ is the thermal conductivity of her skin, 0.37 $Wm^{-1}K^{-1}$ [13], A is the surface area of her body, assumed to be 1.8 m^2 [14], and the thickness of her dermal layers, Δx, will be taken to be 5 mm [15].

To describe the temperature gradient between Kiss-shot and the atmosphere, ΔT, her temperature immediately after jumping, ΔT_i, will be used since Kiss-Shot is far hotter than the temperature of the atmosphere, $\Delta T \sim \Delta T_i$.

$$\Delta Q = \kappa A \frac{\Delta T_i}{\Delta x}\Delta t = 4.57 \times 10^{18} J \quad (5)$$

$$Q_f = Q_i - \Delta Q = 5.58 \times 10^{20} J \quad (6)$$

After subtracting ΔQ, the heat lost whilst travelling from Antarctica, gives a value for Q_f, the heat that evaporated the body of water she landed in. The mass of water, m_w, evaporated can be calculated using Equation 7, where L_w and c_w are the latent heat and specific heat capacity of water, equal to $2.25 \times 10^6\ JK^{-1}$ and 4186 $Jkg^{-1}K^{-1}$ respectively [16]. As the water is vaporised from an estimated ambient temperature of 20 °C to its boiling point, the temperature change of water ΔT_w is 80 K. ΔT_f is Kiss-Shot's temperature change and can be calculated by substituting Q_f in place of Q_i in Equation 4.

$$m_w = \frac{m_s c_s \Delta T_f}{c_w \Delta T_w + L_w} = 1.54 \times 10^{14}\ kg \quad (7)$$

The density of water, ρ, is 998 kgm^{-3} [16] and can be used to convert the mass of water into the volume vaporised, V.

$$V = \frac{m_w}{\rho} = 1.54 \times 10^{11}\ m^3 \quad (8)$$

Carrying an initial 563 EJ of heat from Antarctica, and losing a small fraction during the leap to Japan, would have been enough energy to vaporise a 154 km^3 volume of water. The largest lake in Japan is Lake Biwa with a volume of 27 km^3 [17], meaning any inland volume of water that Kiss-Shot landed in would have been vaporised with ease.

Conclusion

Carrying an unfathomable temperature of over 10^{15} K after jumping from Antarctica – making the trip at hypersonic speeds – Kiss-Shot would be hot enough to vaporise the full 27 km^3 volume of Lake Biwa, the largest lake in Japan, with heat left to spare.

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