

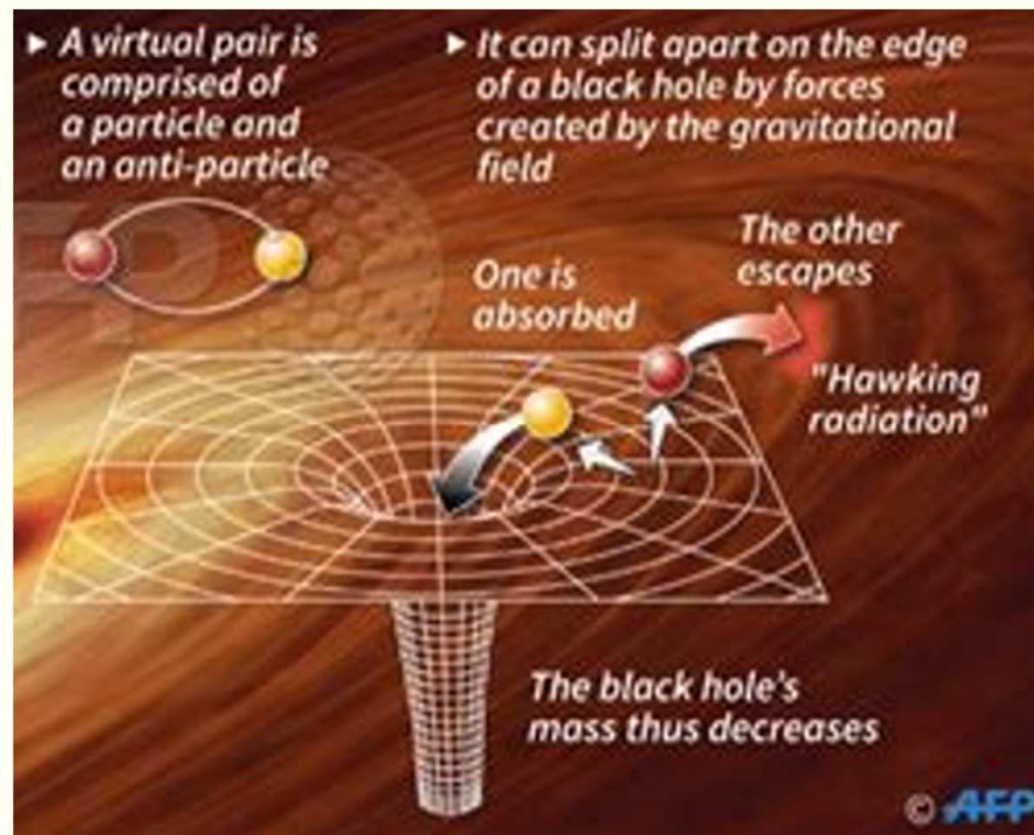


HAWKING RADIATION OVERVIEW

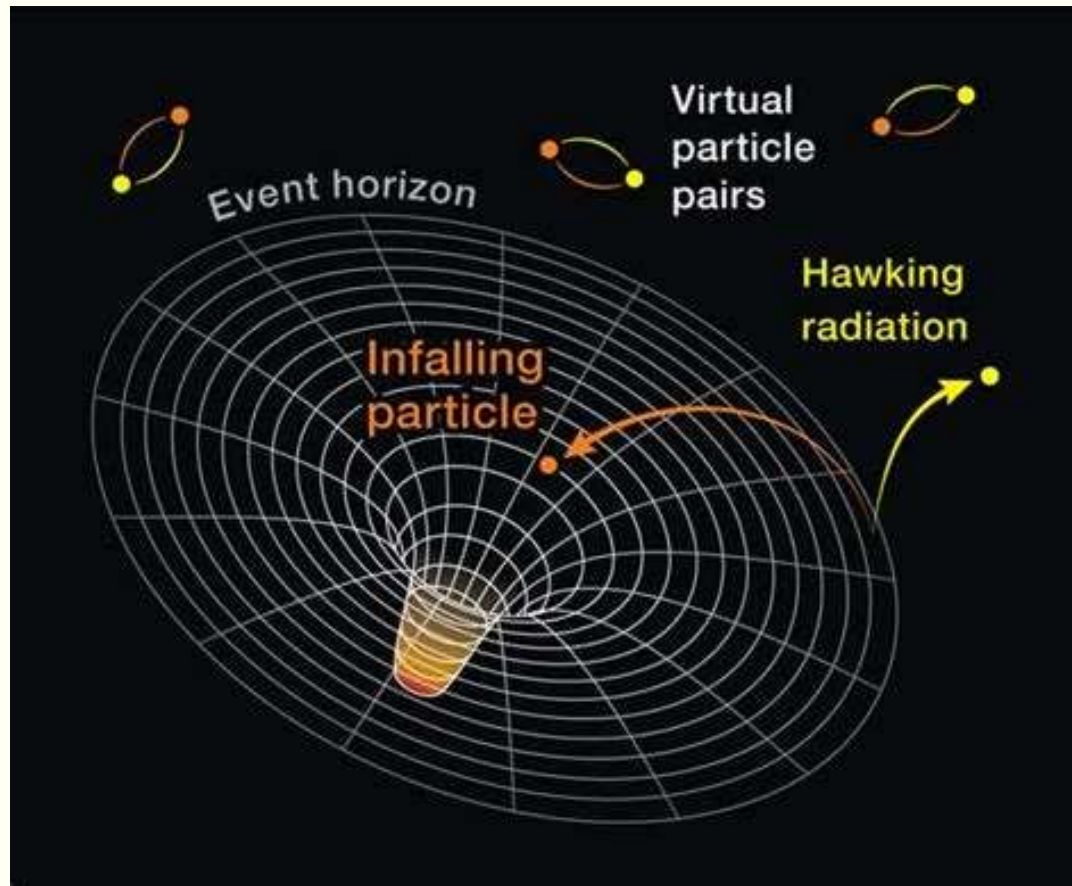
by Robert D. Klauber

Hawking Radiation: The Myth

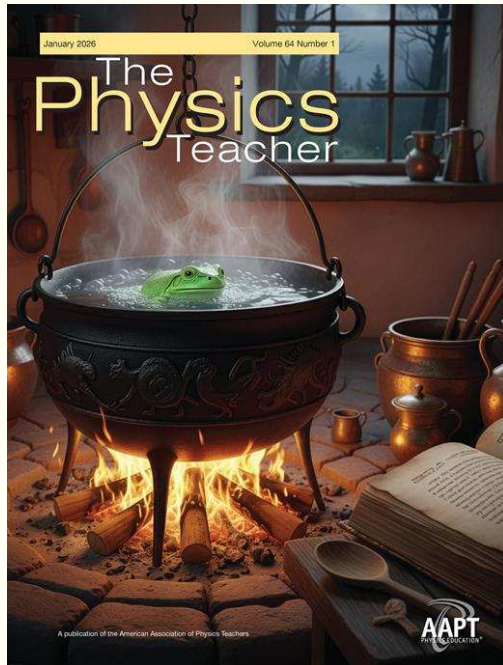
Hawking Radiation: The Myth



Hawking Radiation: The Myth



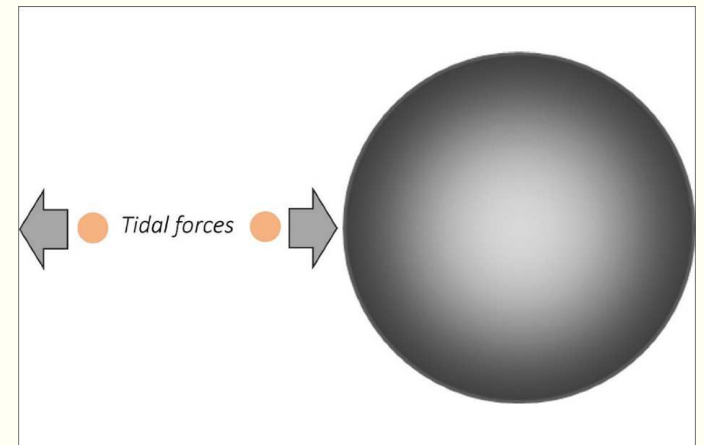
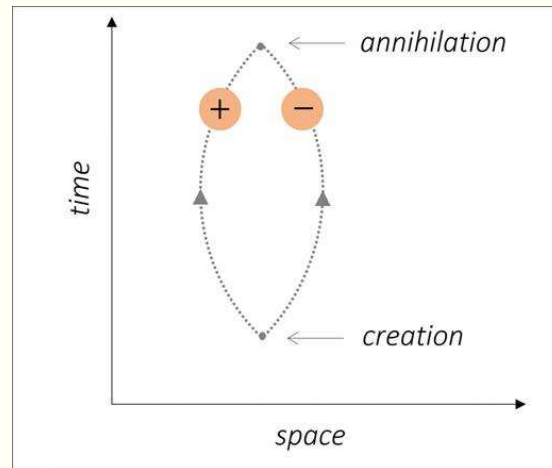
Hawking Radiation: The Myth



Volume 64, Issue 1 January 2026

Hawking for Beginners

Jorge Pinochet 



<https://pubs.aip.org/aapt/pte/article/64/1/16/3375729/Hawking-for-Beginners>

Hawking Radiation: The Myth

BIG THINK

“Nothing” doesn’t exist. Instead, there is
“quantum foam”

When you combine the Uncertainty Principle with Einstein's famous equation, you get a mind-blowing result: Particles can come from nothing.

February 16, 2023



by [Don Lincoln](#), world famous Fermi Lab researcher
with over 1500 publications

“... temporary energy can make matter (and antimatter) particles.”

<https://bigthink.com/hard-science/nothing-exist-quantum-foam/>

Hawking Radiation: The Myth

Quotes from the Big Think article

“...empty space isn't empty. It's actually a vibrant place, with tiny subatomic particles appearing and disappearing in wanton abandon.”

Maybe via ZPE, but not antiparticle/particle pairs.



“One demonstration ... the magnetic properties [magnetic moment] of subatomic particles. ... When ... quantum foam is taken into account, theory and measurement agree — to twelve digits of accuracy.”

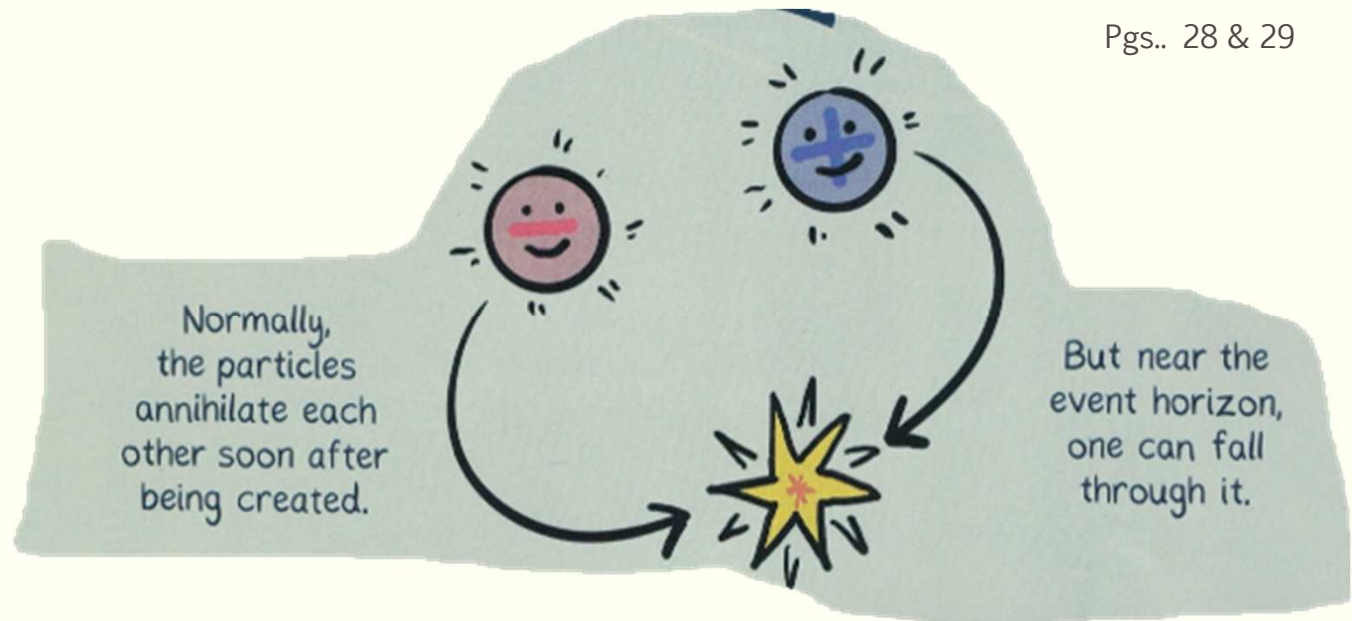
This confuses virtual particles (which cause the anomalous magnetic moment) with vacuum particles.

“Another demonstration of the quantum foam ... the Casimir Effect,”

Not. Casimir can be described with relativistic van der Waals forces.

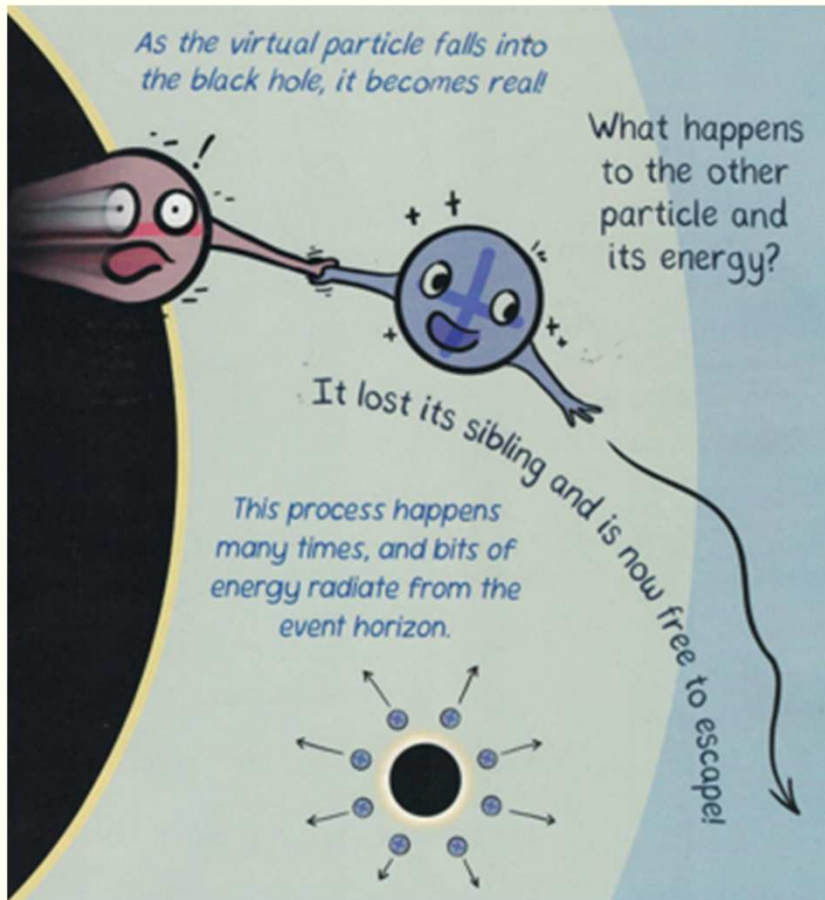
Physics Today April 2026

Uncertainty causes weird effects near the event horizon. Hawking showed how quantum fluctuations allow energy to escape from a black hole, a process now known as Hawking radiation. He described this **heuristically** with virtual particle-antiparticle pairs, here represented with  and  :



Note the word “heuristically” in bold.

Physics Today April 2026



The full physical picture is a bit more complicated, but the net result is the same:

The author seems to know this picture is wrong, but still promulgates it.

Sadly, this is not good science teaching.

Hawking Radiation: The Myth

Hawking radiation from pair popping at event horizon

- Not shown in any texts.
- Not shown in Hawking's original paper on it.
- Yet it is in Hawking's book for lay readers *Brief History of Time*.

Hawking Radiation:

Time to Change the Narrative

Hawking Radiation: Time to Change the Narrative

It's time to stop teaching the biggest lie about Hawking radiation

It's not about particle-antiparticle pairs falling into or escaping from a black hole. A deeper explanation alters our view of reality.

by **ETHAN SIEGEL**

January 15, 2026

<https://bigthink.com/starts-with-a-bang/hawking-radiation-really-work/>

Hawking Radiation: Time to Change the Narrative

Quotes from the Ethan Siegal article

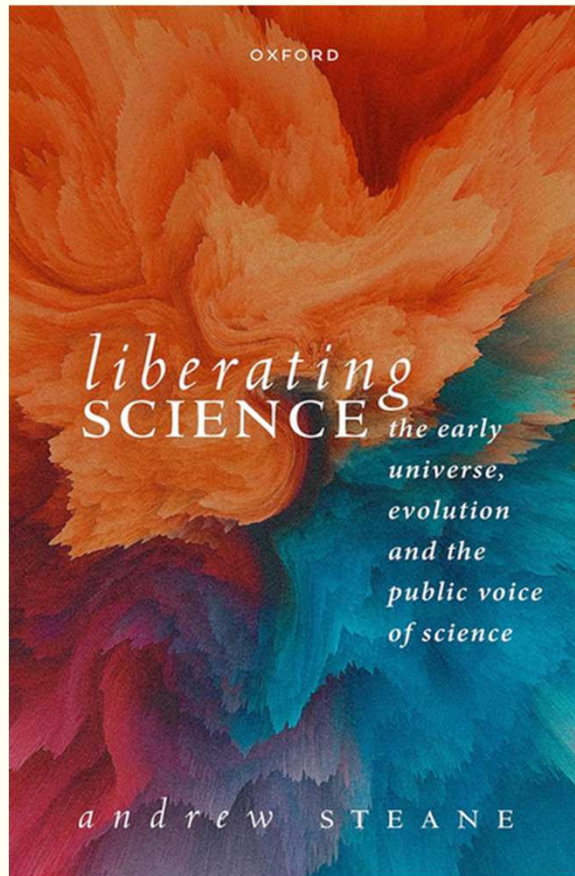
The **idea** that people then run with is that ... [from the Heisenberg uncertainty principle] ... you can create a **particle-antiparticle pair** of quantum particles, spontaneously, **from nothing**.

This oversimplified picture, despite its widespread use, is **completely wrong**.

The idea that the zero-point energy of empty space comes from this “particle-antiparticle popping” is a **complete work of fiction**.

Despite how often this viewpoint has been repeated, and **despite the many prominent voices** that have lent their **support for it, it simply isn't true**.

Hawking Radiation: Time to Change the Narrative



Andrew Steane is a Professor of Physics at Oxford University. He has performed pioneering work in quantum physics and quantum computing, and is the author of three physics textbooks. He received the Maxwell Medal and Prize of the Institute of Physics.

Hawking Radiation: Time to Change the Narrative

Excerpts from Professor Steane's Book

CHAPTER 3

QUANTUM FLUCTUATION?

It is often stated, in popular presentations of physics, that the vacuum of space is full of 'quantum fluctuations'. It is said that the fields I described in the previous chapter are always and everywhere in a state of fluctuation. Sometimes it is said that particles and antiparticles are continually 'popping out of the vacuum' and then quickly vanishing again. Sometimes space is said to be a seething mass of such behaviours. Countless books and lectures talk freely about 'jitter', 'bubbling and rippling' etc.

This picture is wrong.

CHAPTER 4

THE VACUUM AS A DYNAMICAL SYSTEM

In the previous chapter I introduced the symbol $|\Omega\rangle$ to refer to the situation for the collection of quantum fields in their lowest energy state. In this state there are no particles, and furthermore, no particle-antiparticle pairs ever suddenly appear and then quickly disappear again. So why have many people asserted that they do? It is because they are trying to convey to the layperson not fluctuate is called fluctuation. But if we allow ourselves to speak as loosely as that, then we will not be undertaking science communication; we will be doing something else: passing off as science that which is not faithful to science. The calculational

Background: Hawking Radiation

QFT and General Relativity

Distinguish between:

- Quantum gravity (gravity, e/m, weak, strong all quantum)
- QFT in curved spacetime (gravity is classical, e/m, weak, strong all quantum)

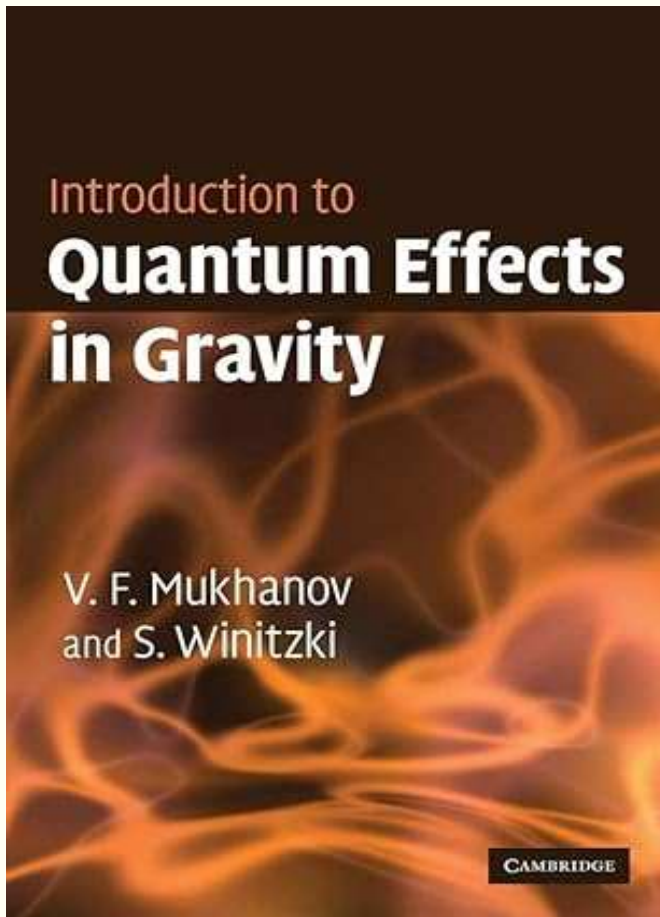
Status of theories:

- Quantum gravity (QG): no complete theory (though strings promising)
- QFT in curved spacetime: We can do this with present theory, GR and QFT.

Limitations of QFT in curved spacetime:

- Good for weak gravity. Need QG for strong gravity field.
- Using near black holes may be OK, but questions arise.

Text We Will Refer To



This book covers QFT in curved spacetime, not QG.

It's not bad, as physics texts go, but dense in places.

Pedagogic aids to help in studying this book available at https://www.quantumfieldtheory.info/Quant_Fields_in_GR_overview.htm

Sample Derivation from M&W

Page 51 from M&W showing one step between two equations.

the magnitude of fluctuations, let us calculate the correlation function

$$\xi_{\phi}(|\mathbf{x} - \mathbf{y}|) \equiv \langle 0 | \hat{\phi}(\mathbf{x}, t) \hat{\phi}(\mathbf{y}, t) | 0 \rangle .$$

Substituting the mode expansion (4.22), we obtain

$$\xi_{\phi}(|\mathbf{x} - \mathbf{y}|) = \frac{1}{4\pi^2} \int \frac{k^3}{\omega_k} \frac{\sin(k|\mathbf{x} - \mathbf{y}|)}{k|\mathbf{x} - \mathbf{y}|} \frac{dk}{k} ,$$

Klauber pedagogic aids document for this chapter takes 2½ pages for this derivation.

http://www.quantumfieldtheory.info/Vac_Flucts_as_Correl_Functs_M&W_Chap4_Notes.pdf .

M&W Approach

- Chaps. 1-4: Intro/**review** of QFT in inertial frames (Minkowski metric).
- Chap. 5: **Classical** fields in classical GR. Form of field equations in GR (general metric).
- Chap. 6: **Quantization** of above fields. **Transformation from inertial to non-inertial** frame (Bogolyubov transformations). Application to expanding universe.
- Chap. 7: QFT in **de Sitter universe**.
- Chap. 8: **Unruh** (Davies/Fulling/Unruh) radiation. **QFT in accelerating system**.
- Chap. 9: **Hawking radiation**.

Hawking radiation deduced using **equivalence principle and Unruh radiation** result. Unruh radiation in accelerating frame equivalent to Hawking radiation stationary to black hole.

Unruh Radiation

Bottom Line: Unruh Radiation



Inertial frame

No vacuum particles/radiation

Bogolyubov transformation



Accelerating frame

Vacuum particles/radiation

Key Steps for Unruh Radiation

1. Take **usual solutions** to field equations in **Minkowski** space.
2. **Convert to** special 4D coordinate system called **light cone coordinates**. Presumably this makes solving easier (but it's harder to visualize what happens).
3. Deduce the **transformation** from light cone (inertial system) coordinates **to accelerating** frame coordinates. This is the **Bogolyubov transformation**.
4. **Use this** transformation to get fields (**solutions to field equations**) in terms **of accelerating** observer.
5. **Find vacuum** for accelerating observer, called the **Rindler vacuum** $|0_R\rangle$, as opposed to the Minkowski vacuum of inertial observer $|0_M\rangle$. Note, analysis assumes no ZPE in $|0_M\rangle$.
6. **Find number operator** for **accelerating observer** \hat{N}_Ω . similar to how we do in usual QFT.

Key Steps for Unruh Radiation, Part 2

7. Find particle number expectation value for accelerating observer looking at Minkowski vacuum.

$$\langle 0_M | \hat{N}_\Omega | 0_M \rangle = \langle \hat{N}_\Omega \rangle \neq 0$$

8. Find particle number density

$$n_\Omega = \frac{\langle \hat{N}_\Omega \rangle}{V} = \left(e^{\frac{2\pi\Omega}{a}} - 1 \right)^{-1} \quad \Omega = \text{particle frequency} \quad a = \text{acceleration}$$

This is interpreted as the **number density** of particles (photons) seen by the **accelerating observer**. It is a Bose-Einstein distribution.

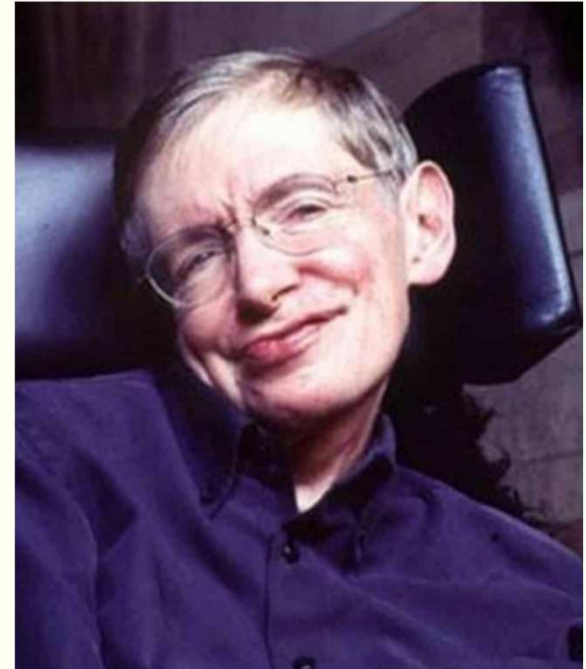
9. Bose-Einstein temperature, calculated from above in stat mech with Boltzmann constant k , is

$$T = \frac{a}{k2\pi} \quad \text{in natural units} \quad T = (1.60 \times 10^{-17}) a \quad \text{MKS units}$$

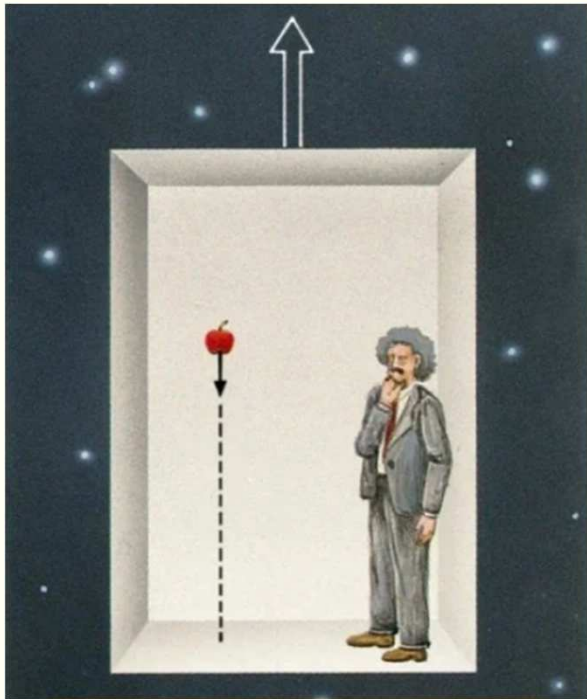
Things to Note for Unruh Radiation

- Massive particles are extremely hard to manifest (much more energy needed), so particle bath is **essentially exclusively photons**.
- The radiation is **black body** with photons appearing to come isotropically from **ALL directions, not just the direction of acceleration**.
- **Radiation just appears under acceleration**. Not there for inertial frame at same location.
- For an acceleration of **1 g**, the temperature is about 1.6×10^{-16} K.
- You would need an acceleration of **16 quadrillion times g** for **1^oK** temperature.
- **No one** has yet come **close** to finding this **experimentally**.

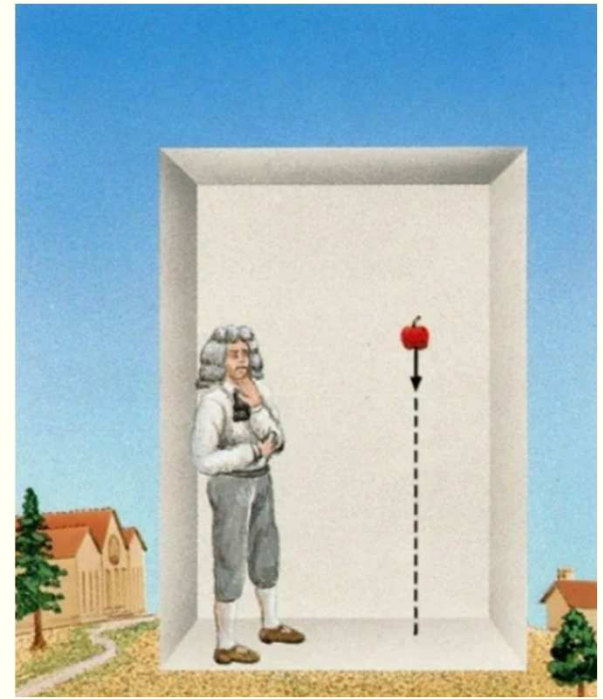
Hawking Radiation



Bottom Line: Hawking Radiation



Equivalence Principle



Non-inertial accelerating frame

Apple accelerates to floor

Non-inertial Earth frame

Apple accelerates to floor

Bottom Line: Hawking Radiation, Part 2



Equivalence Principle



Accelerating frame

Unruh radiation

Fixed in space near black hole

Effective Unruh radiation

= Hawking radiation

Key Steps for Hawking Radiation

1. Apply **equivalence principle**, so Hawking radiation equivalent to Unruh radiation.
2. **Convert** sequentially **to different** (complicated) **coordinate systems** (light cone, Kruskal-Szekeres) to make solving easier. We don't look at this here.
3. Assume **acceleration of gravity** at some point around black hole is κ . Then using **Unruh temperature** relation

$$T = \frac{\kappa}{k2\pi} \text{ in natural units} \quad k = \text{ Boltzmann constant} \quad \kappa = \text{ local acceleration of gravity}$$

4. At **event horizon** $r_{BH} = 2M$, and $\kappa = 1/2r_{BH}$, so $\kappa = 1/4M$, and with that in above,

$$T_H = \frac{1}{k8\pi M} \text{ in natural units}$$

5. With thermodynamic reasoning, one **can show BH entropy** (where A is area at horizon), in natural units

$$S_{BH} = \frac{A}{4} = 4\pi M^2$$

Points to Note for Hawking Radiation

- Massive particles are extremely hard to manifest (much more energy needed), so particle bath is **essentially exclusively photons**.
- The radiation is black body with photons appearing to come from **ALL directions, not just** the direction of **gravity vector**.
- The **radiation is emitted everywhere in space** around the black hole, **not just** at the **event horizon**. The closer to the horizon, the greater the amount of radiation.
- The radiation is **NOT due to particle/antiparticle pairs** at the horizon.

Points to Note for Hawking Radiation, Part 2

- The radiation is **NOT due to ZPE** (though you sometimes see that said) as the analysis began by assuming $ZPE = 0$ in the inertial frame.
- This radiation is **seen by someone fixed relative to the black hole**. A free falling (inertial) observer falling into the black hole would **not see Hawking radiation**.
- **Temperature is inversely proportional to mass**,
so large black holes are low temperature (and thus radiate more slowly);
smaller black holes are higher temperature (and radiate faster).
- **No one** has yet come **close** to finding this **experimentally**.

The Physics and Math Behind Hawking Radiation

Truly understanding this requires a course in QFT in (classical) GR frames.

Recommended: M&W with Klauber notes on his book website (link shown earlier).

Final note: Hawking radiation **assumes contemporary physics is good at high spacetime curvature**, as near the horizon of a black hole.

That assumption **may not hold**.

Hawking Radiation Overview

Thank you!