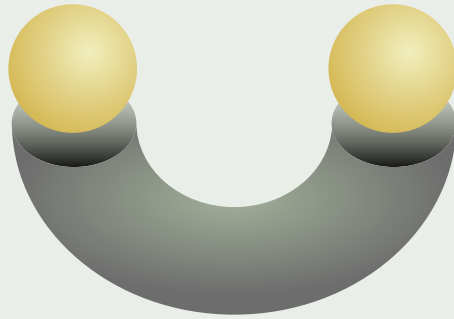


Entanglement, wormholes, and all that



*David Wakeham*

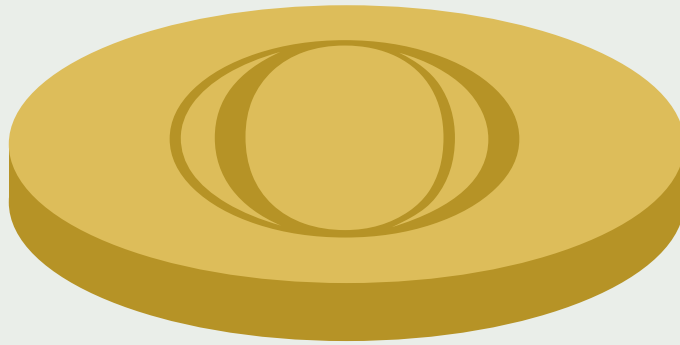
Entanglement, wormholes, and all that

*David Wakeham*

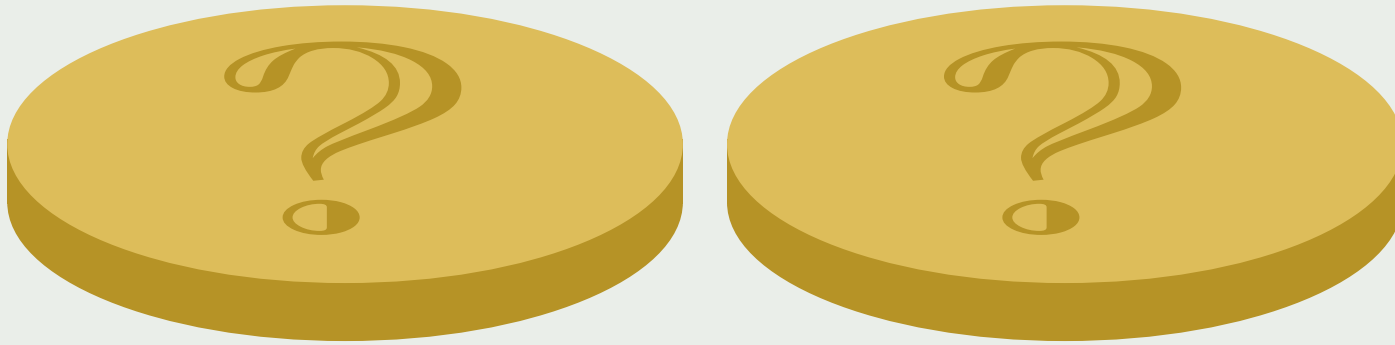
Rather than quantum mechanics,

Rather than quantum mechanics,  
let's discuss the mechanics of **flipping coins**.

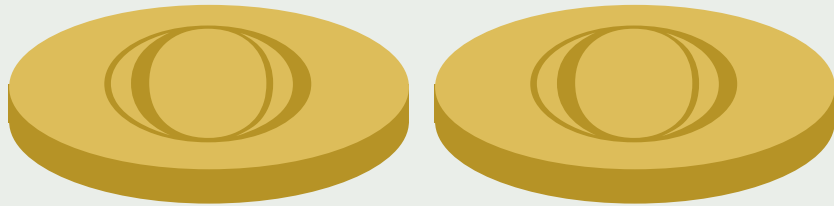


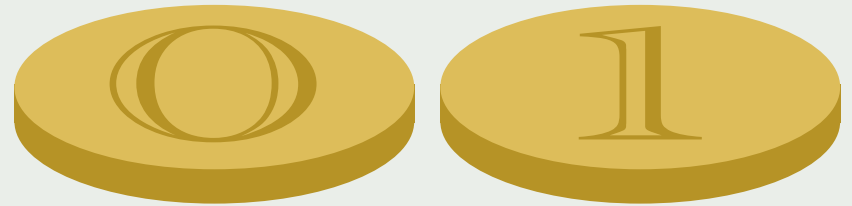
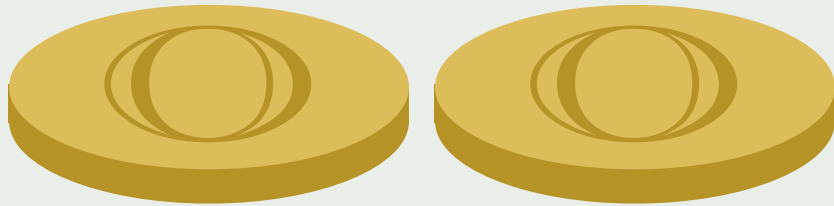


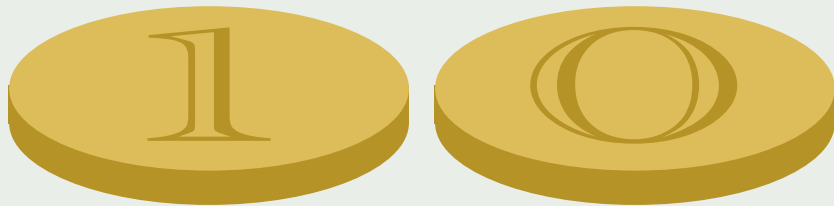
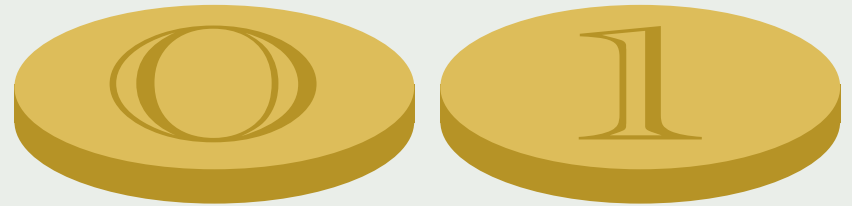
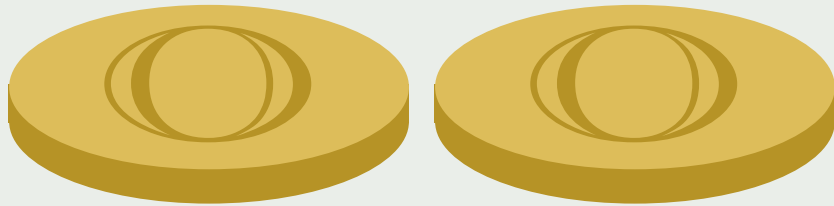


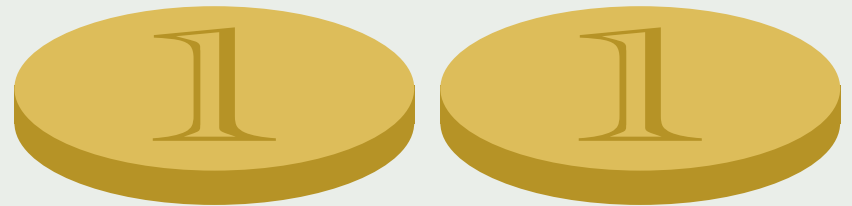
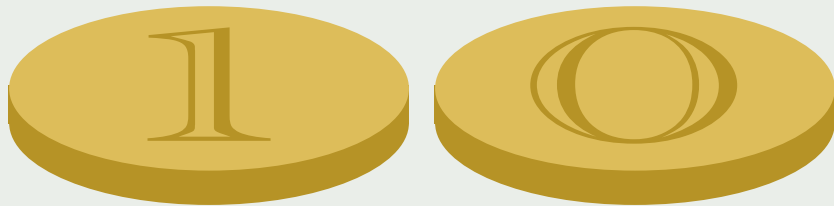
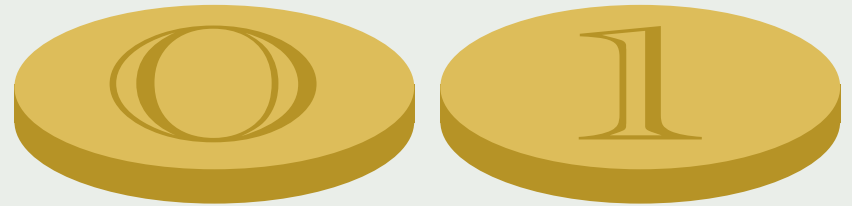
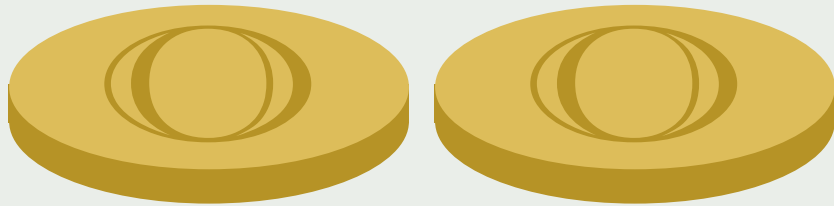


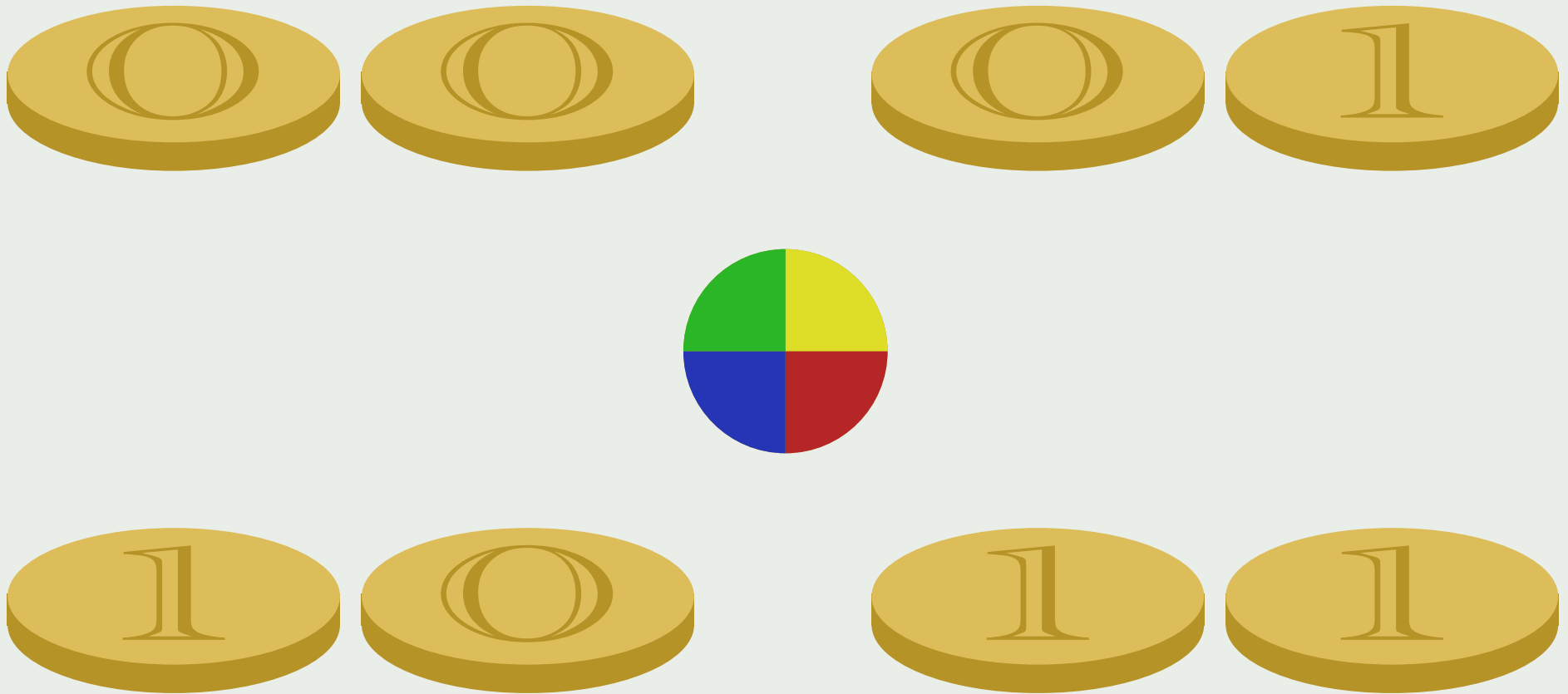












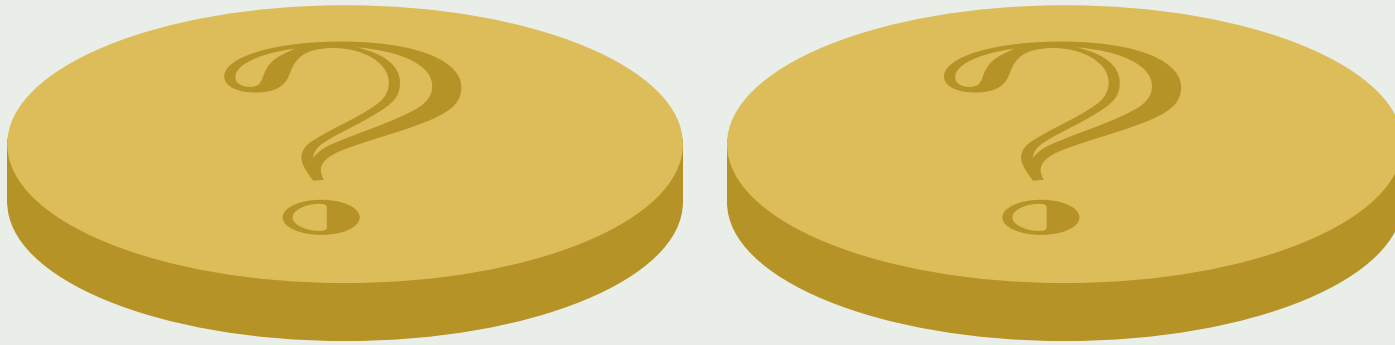
Entanglement, wormholes, and all that

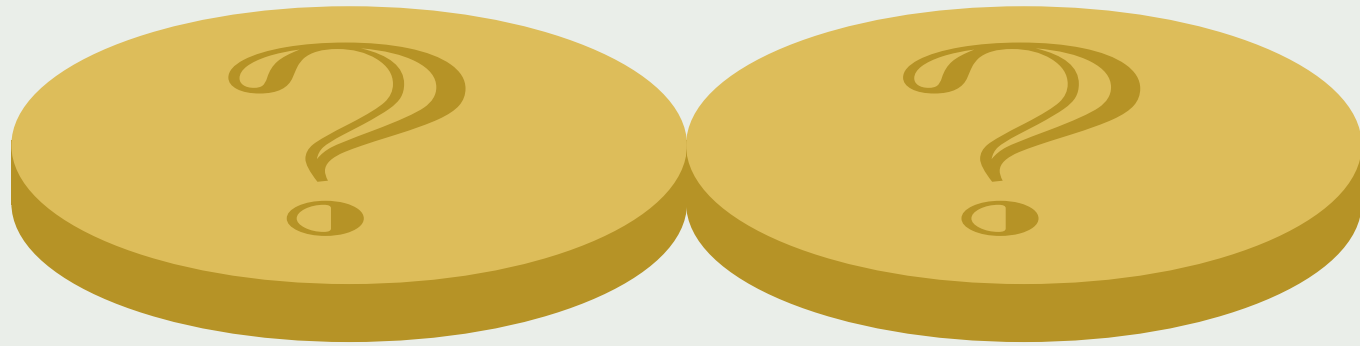
*David Wakeham*

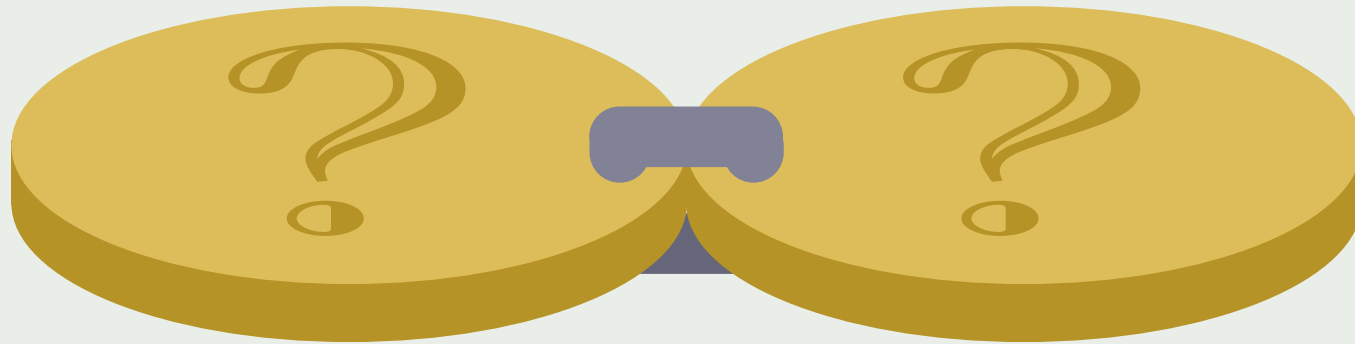
Suppose we **staple** two coins together.

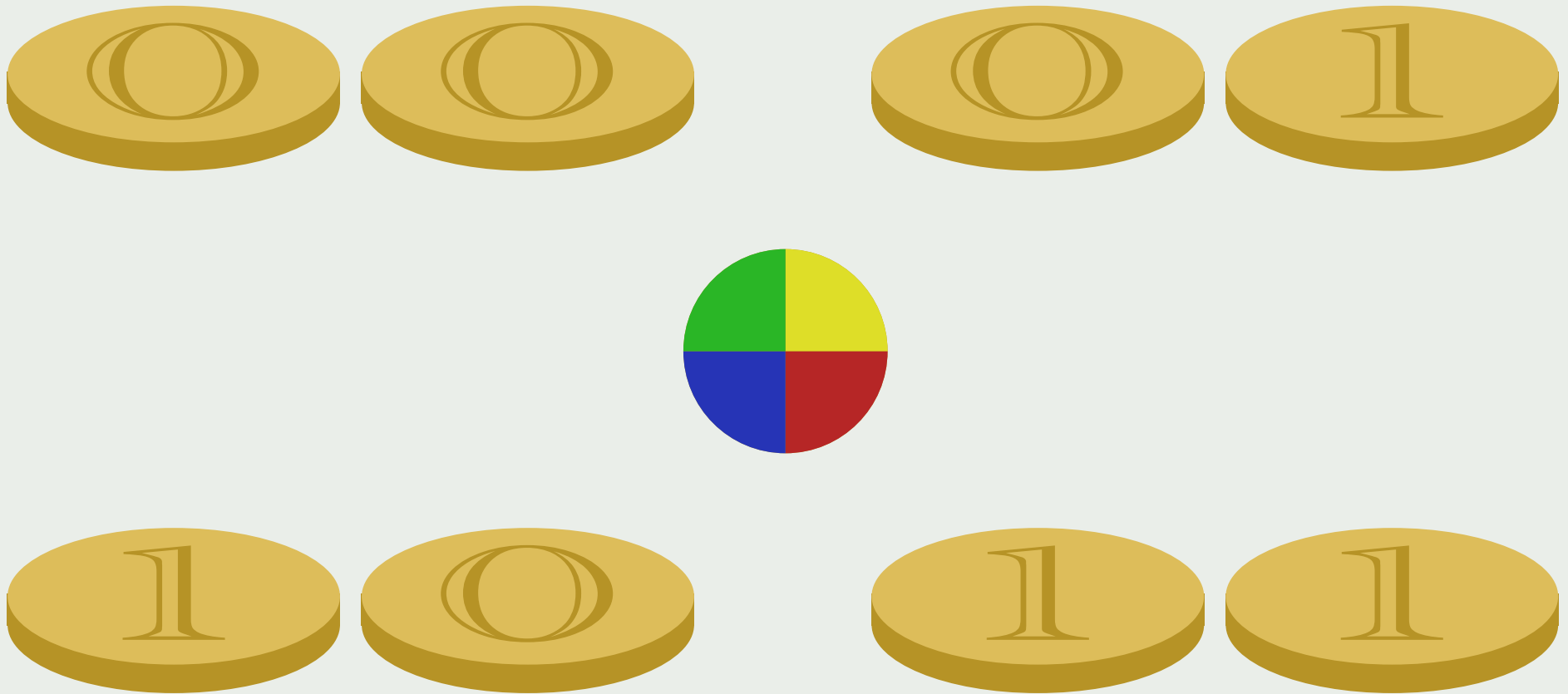
Suppose we **staple** two coins together.  
This restricts the outcome of coin tosses.

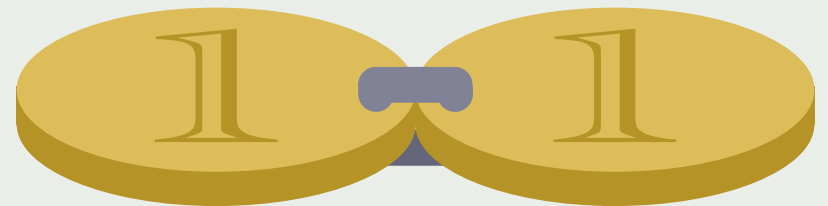
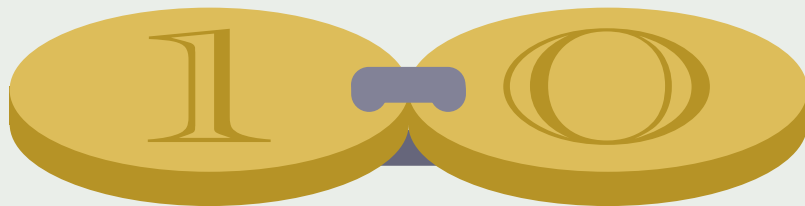
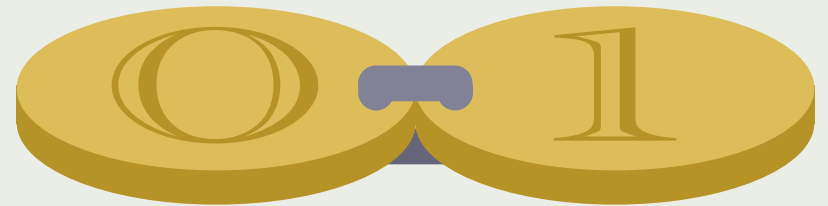
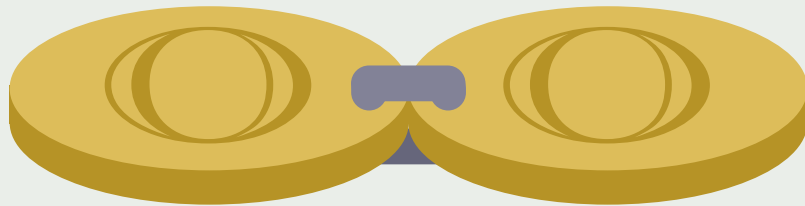


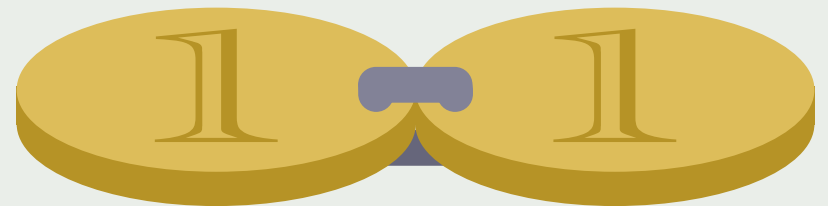
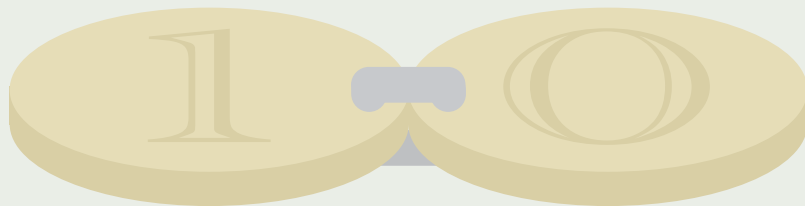
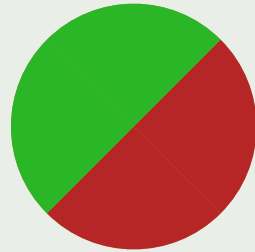
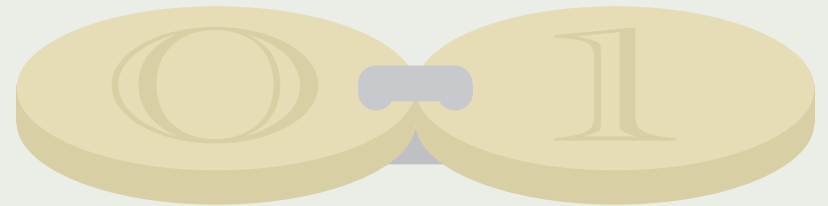
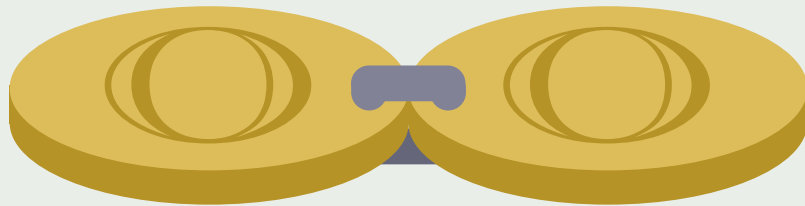


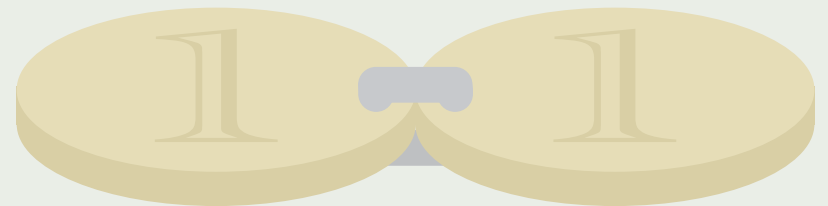
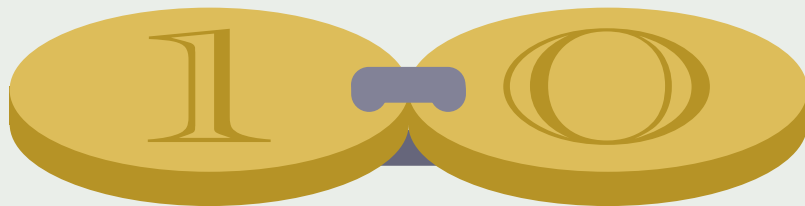
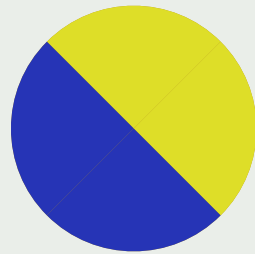
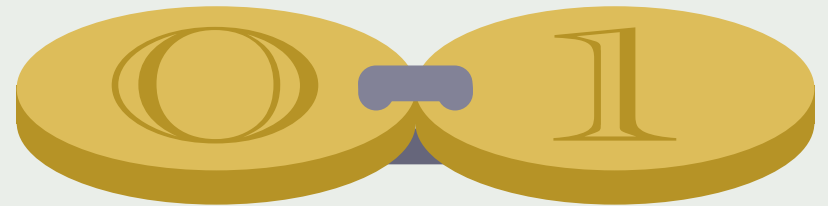
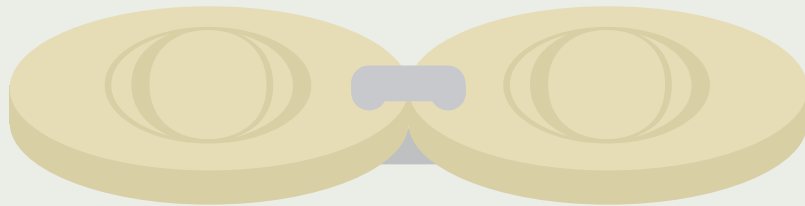












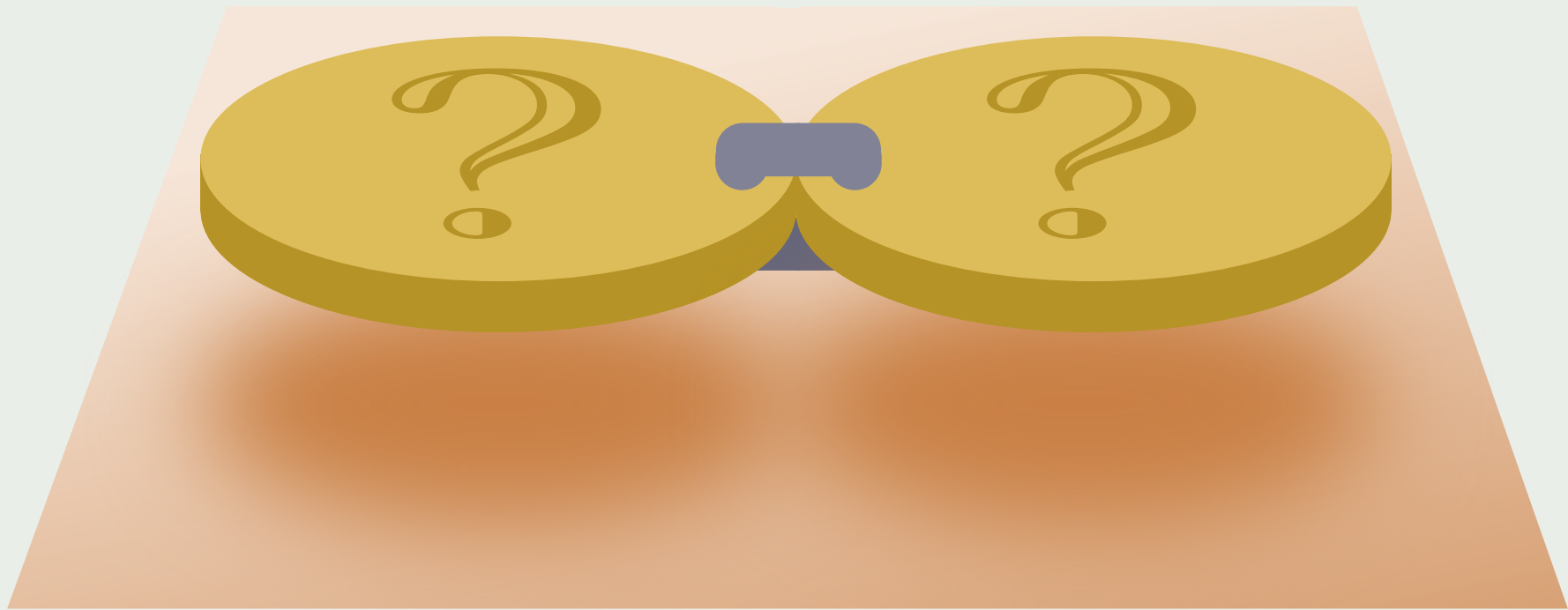
Entanglement, wormholes, and all that

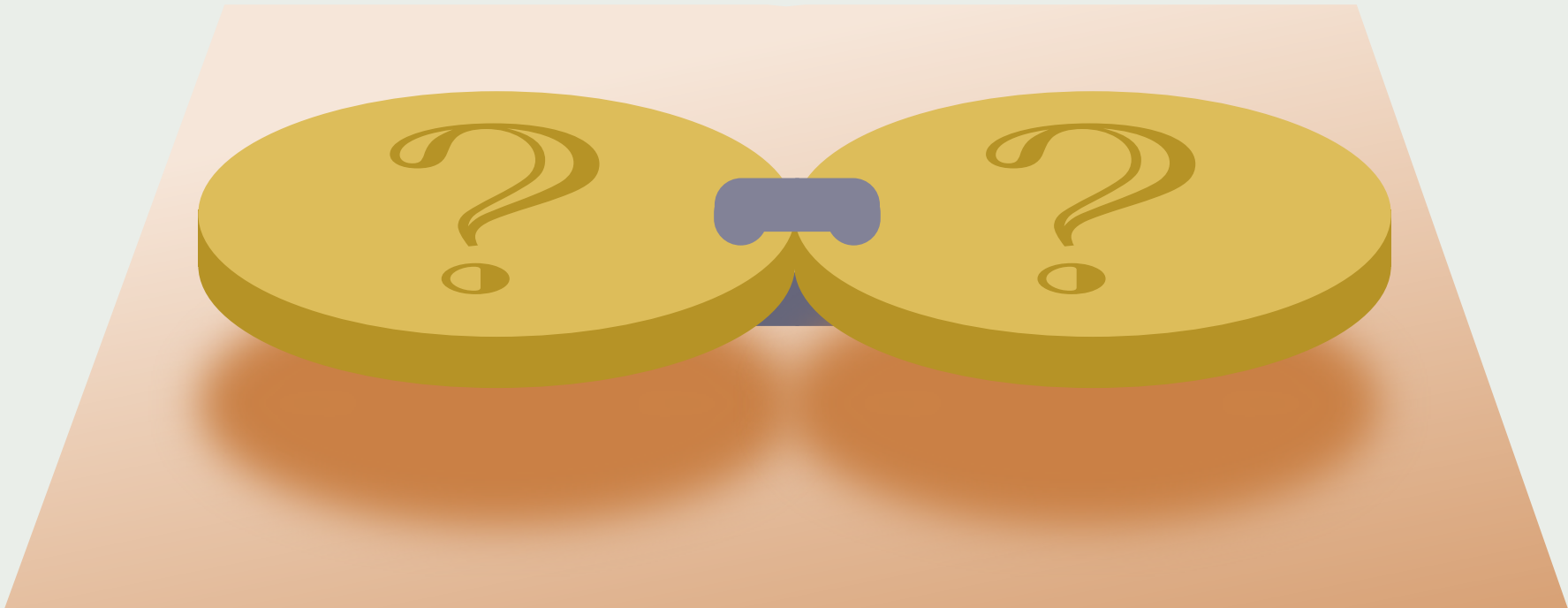
*David Wakeham*

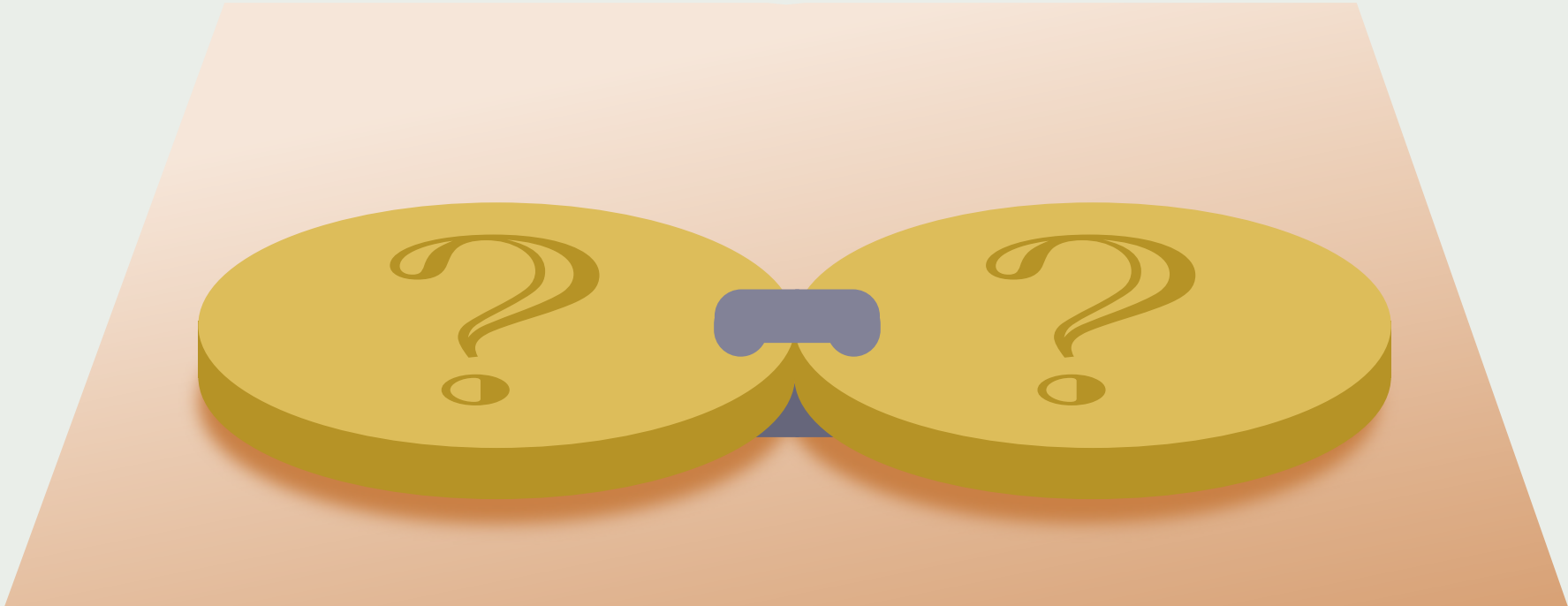


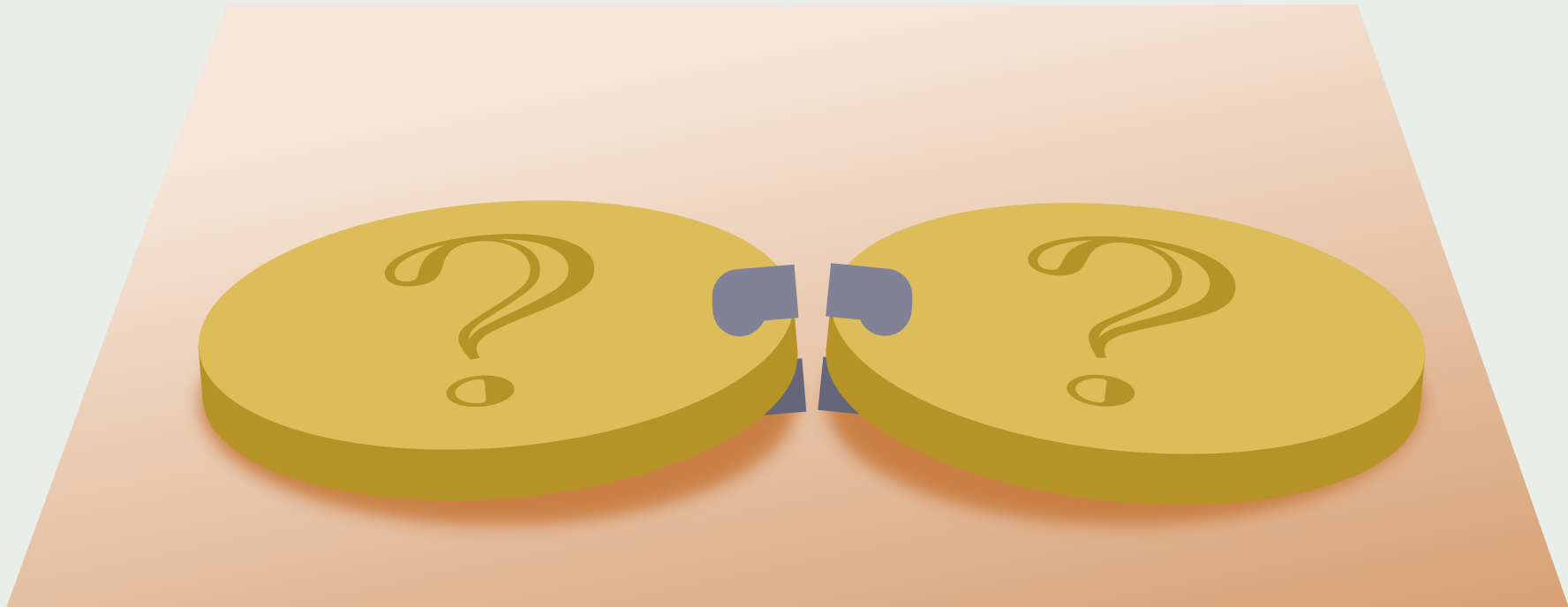
To better model the quantum world,

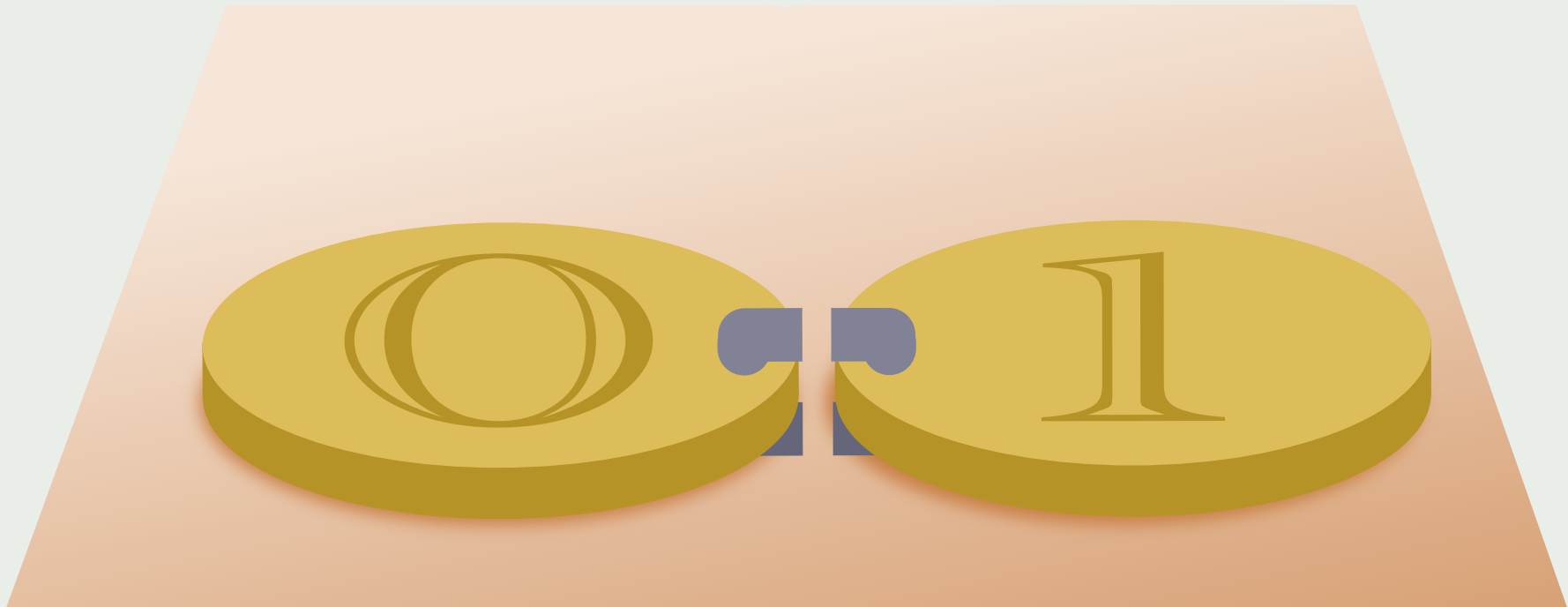
To better model the quantum world,  
suppose the staple **breaks on impact.**

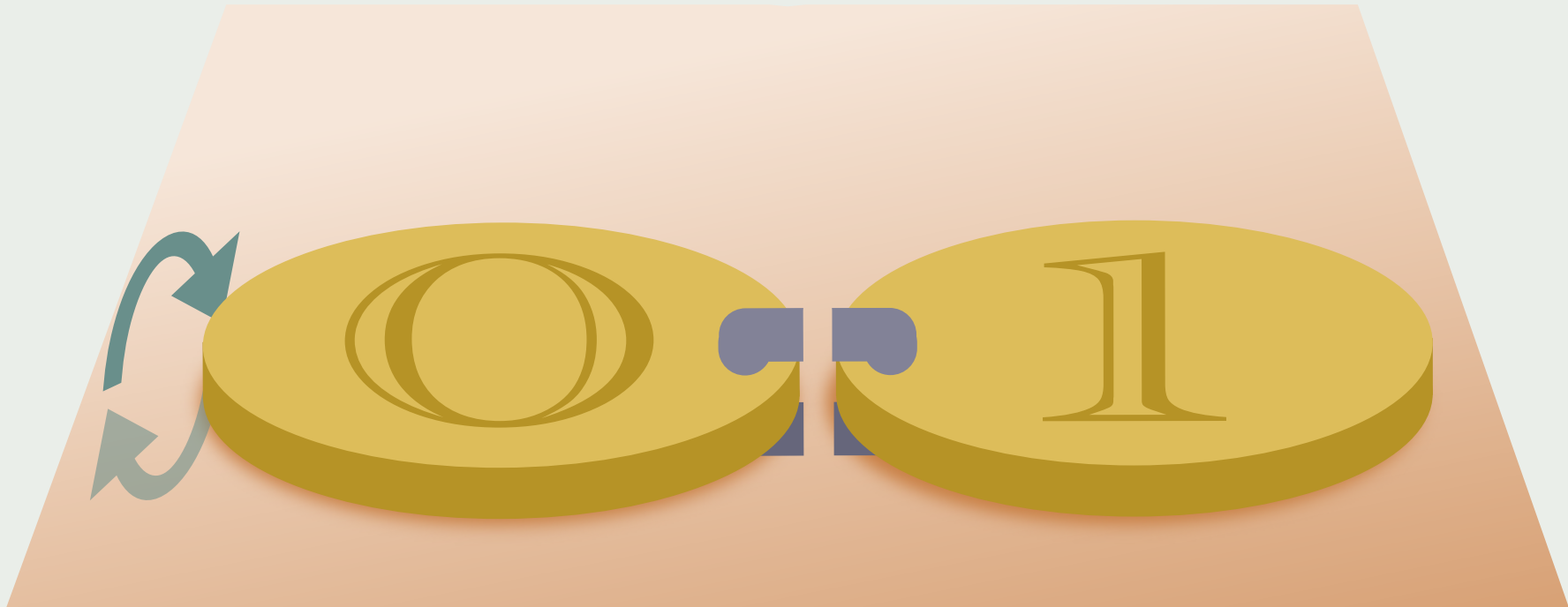




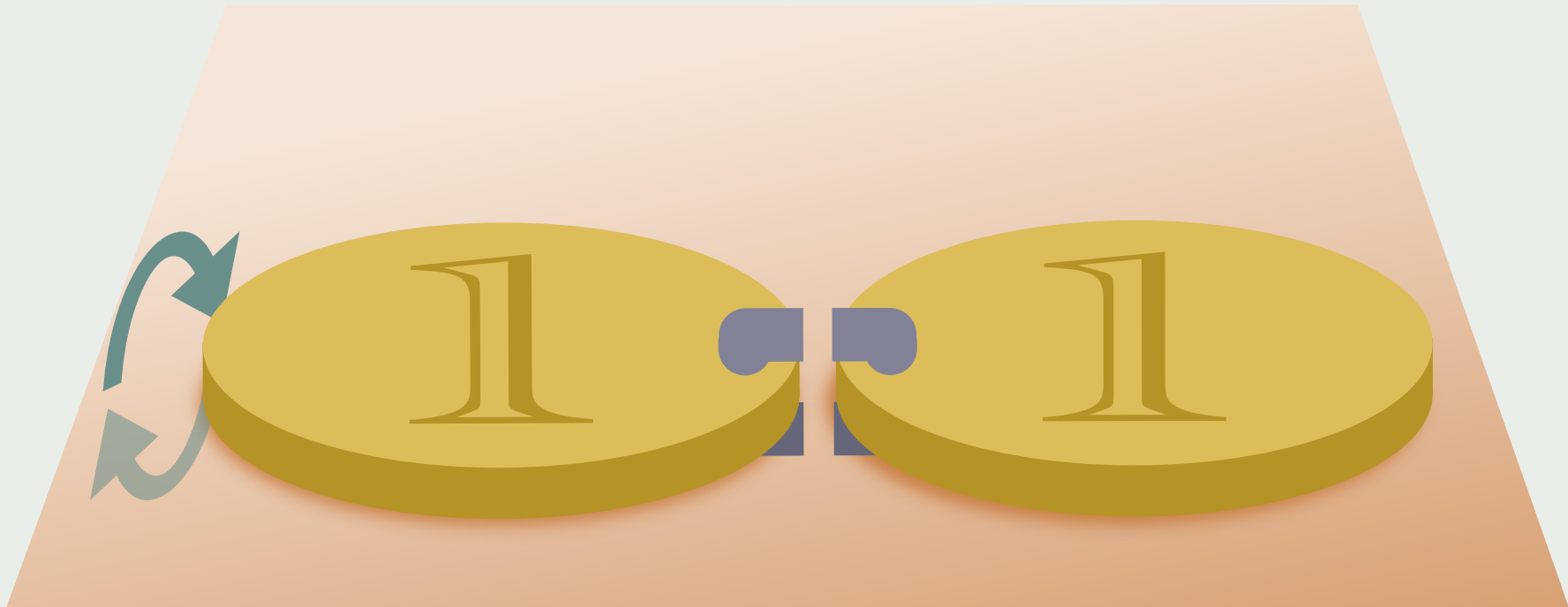








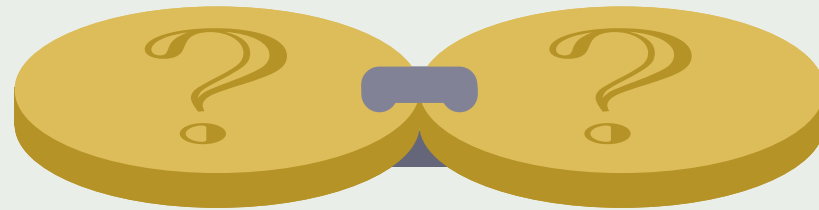




Entanglement, wormholes, and all that

*David Wakeham*

Suppose the staple is *very long*.







Entanglement, wormholes, and all that

*David Wakeham*

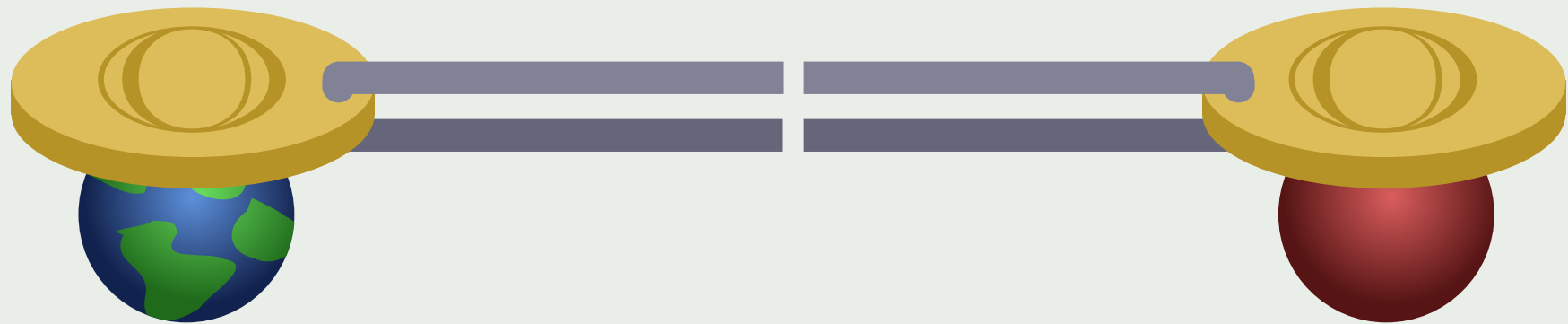
# Flipping the coin on earth

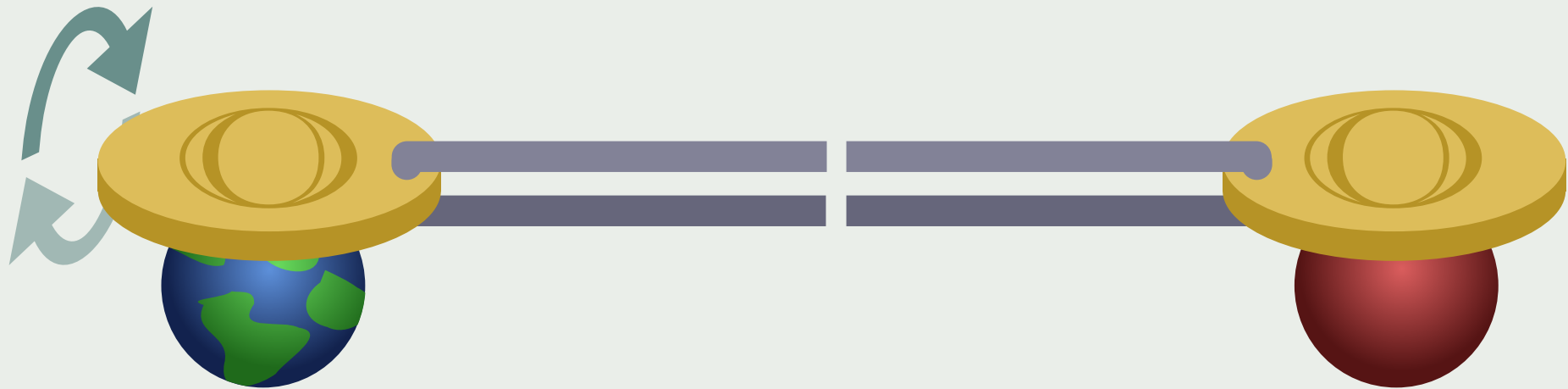


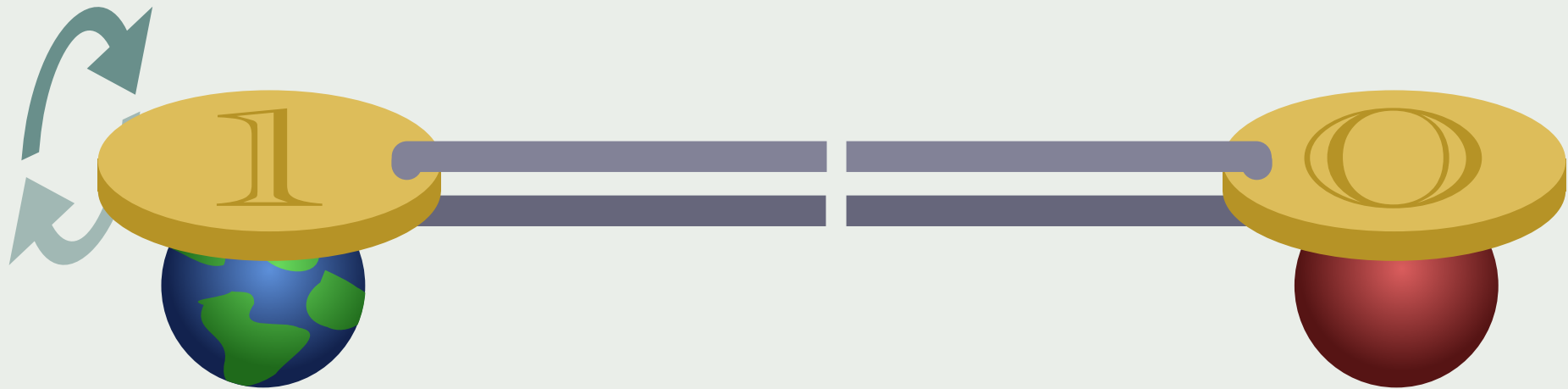
Flipping the coin on earth  
tells you the value on Mars.

Flipping the coin on earth  
tells you the value on Mars.  
But you no longer control it.









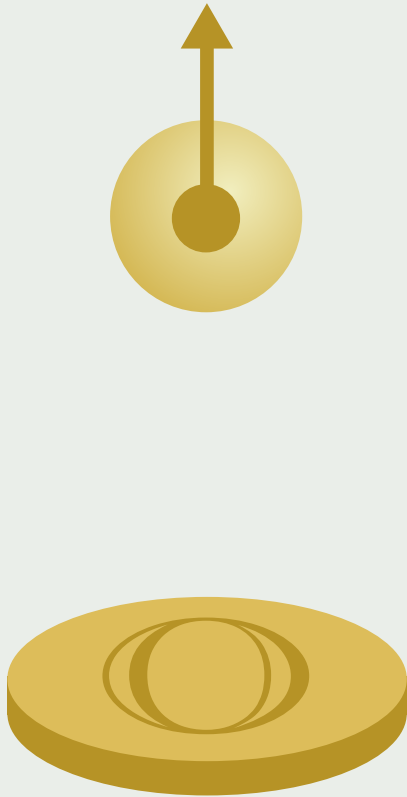
Entanglement, wormholes, and all that

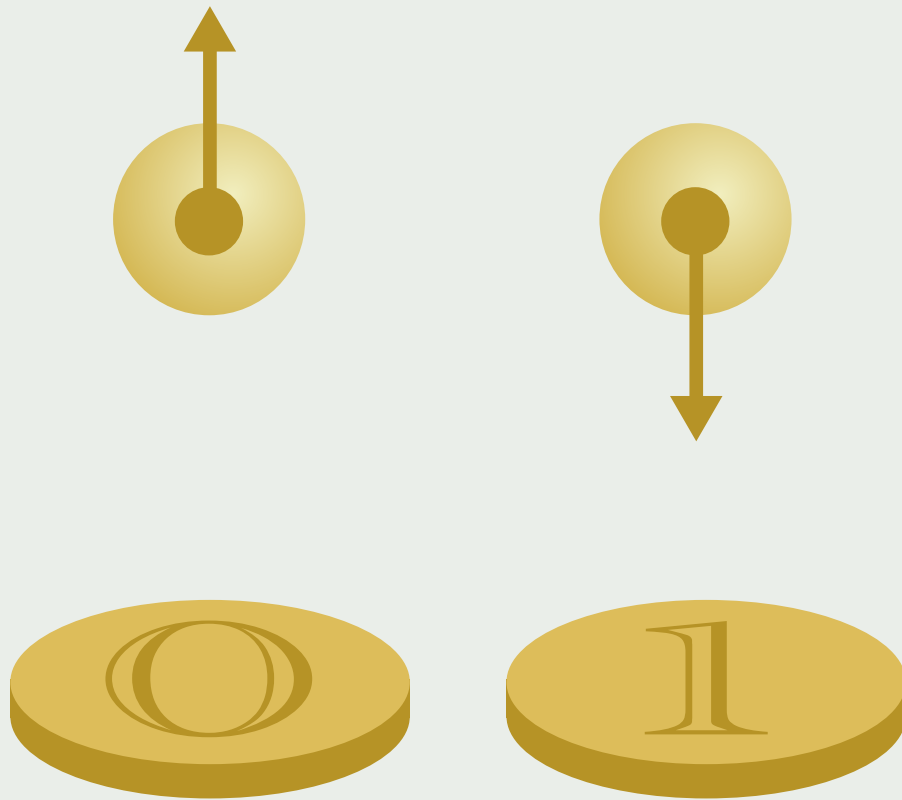
*David Wakeham*

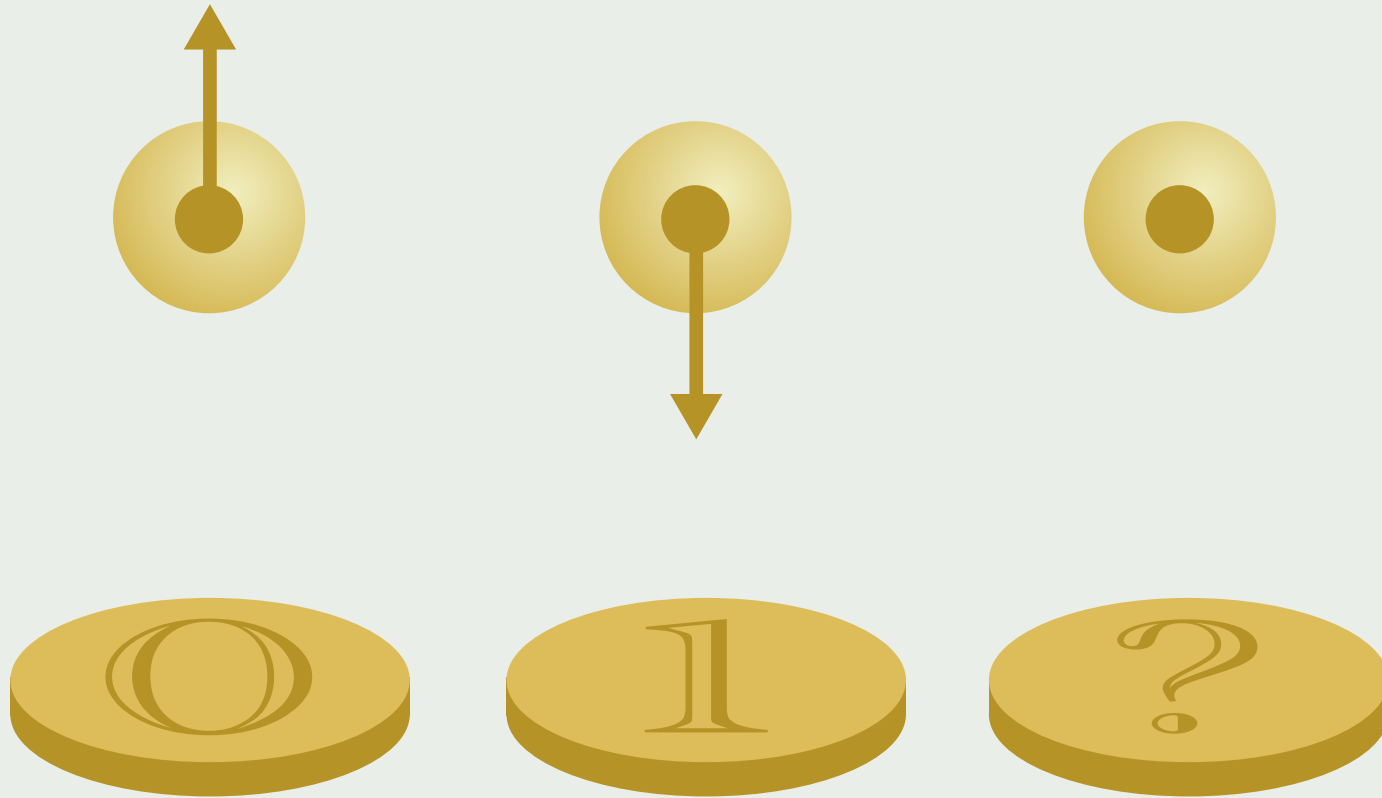
Quantum entanglement is similar.

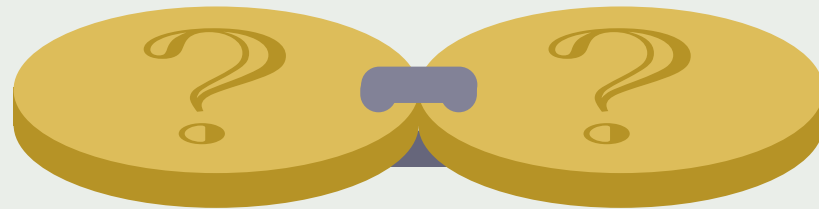
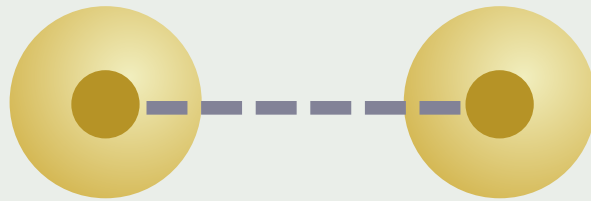


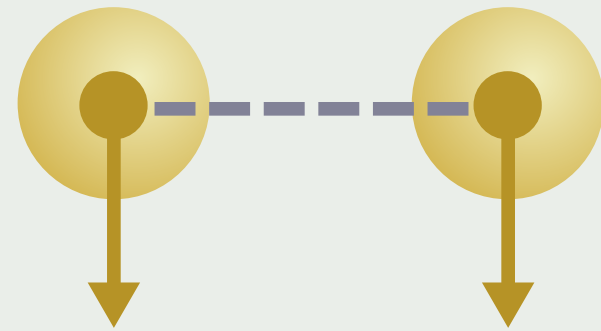
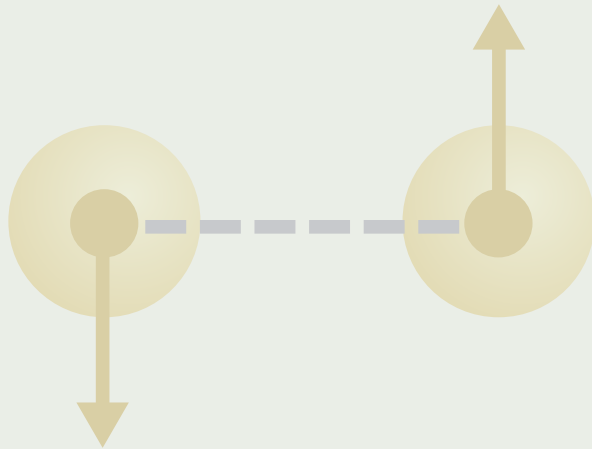
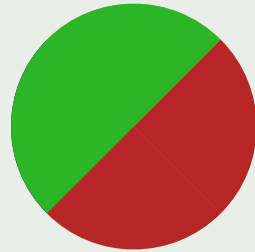
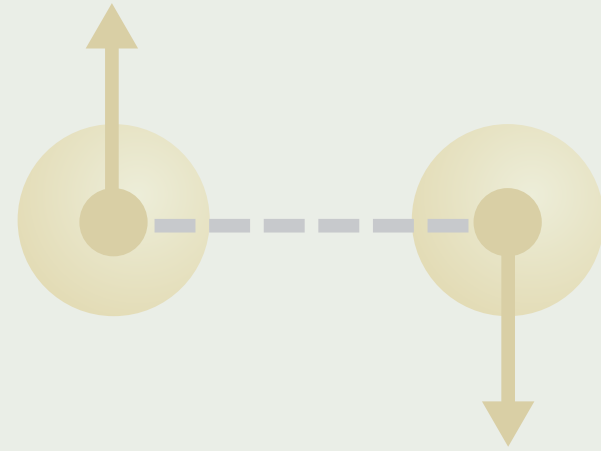
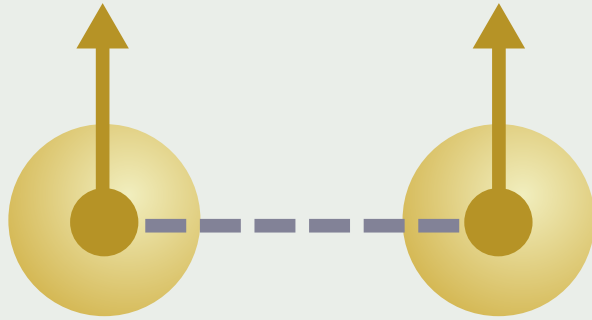
Quantum entanglement is similar.  
Instead of coins, we entangle spins.

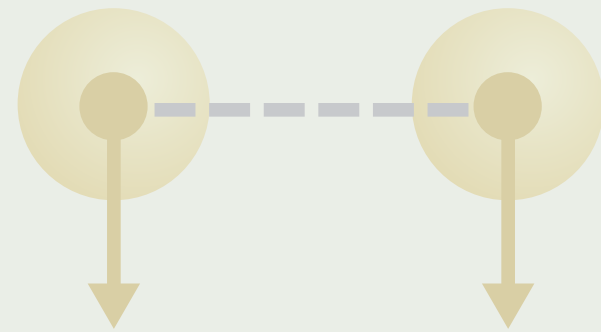
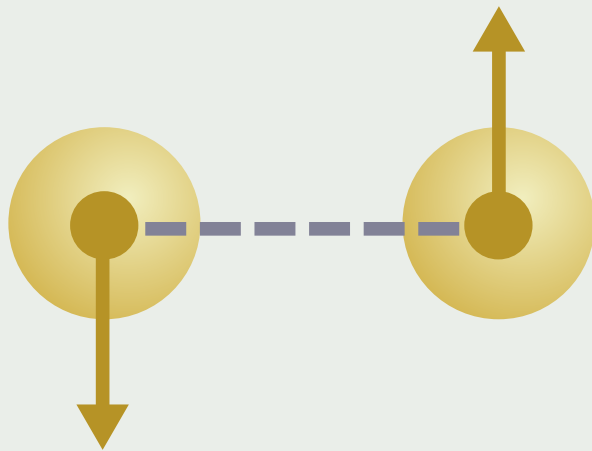
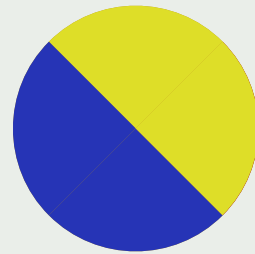
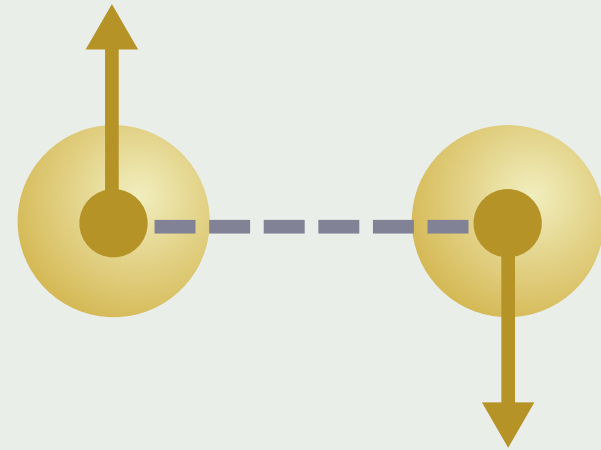
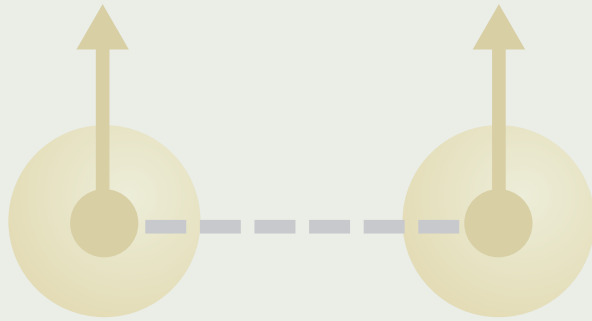


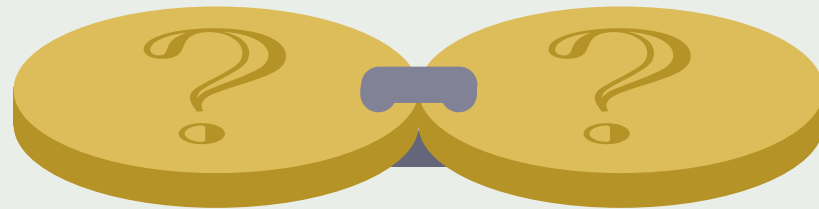
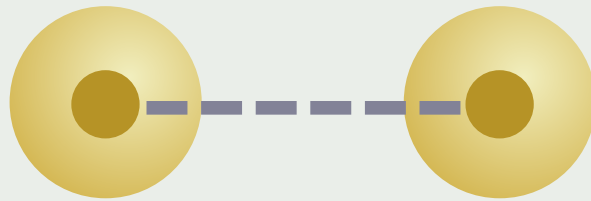






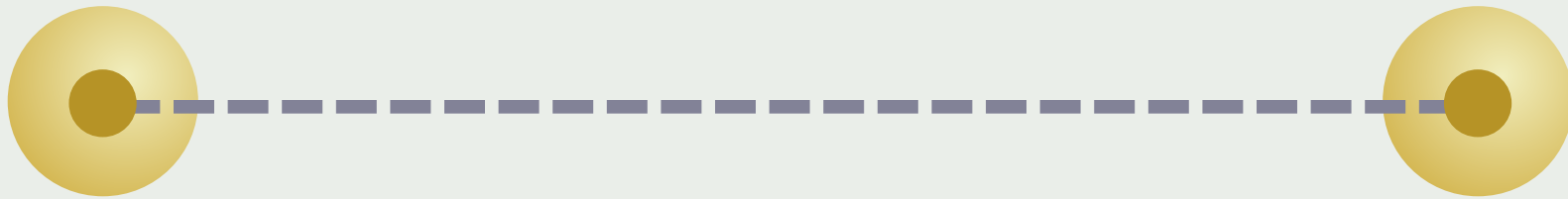




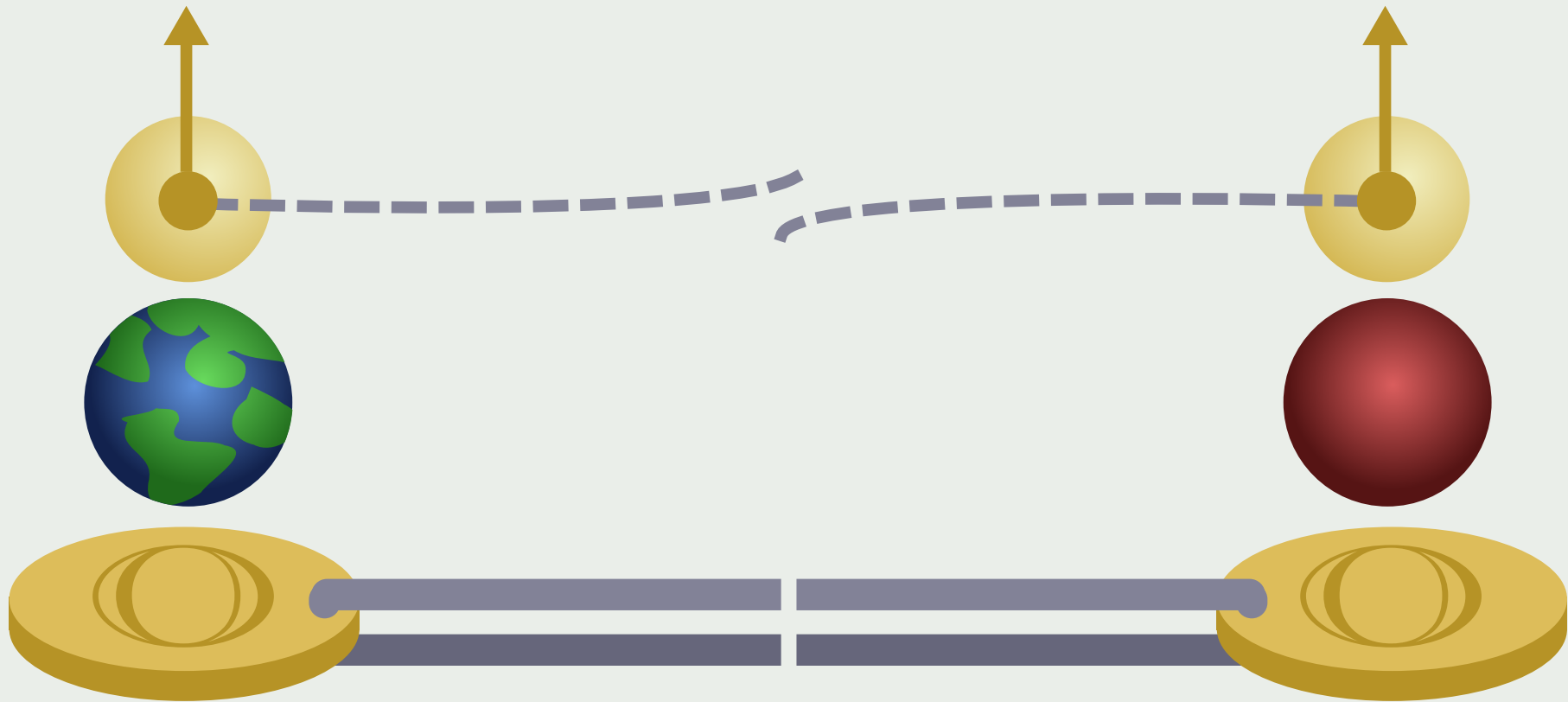










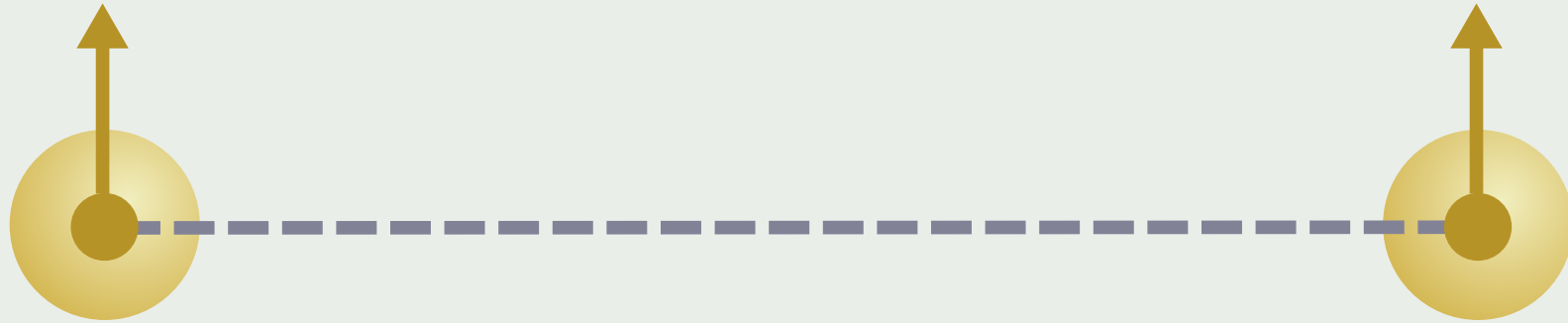


Entanglement, wormholes, and all that

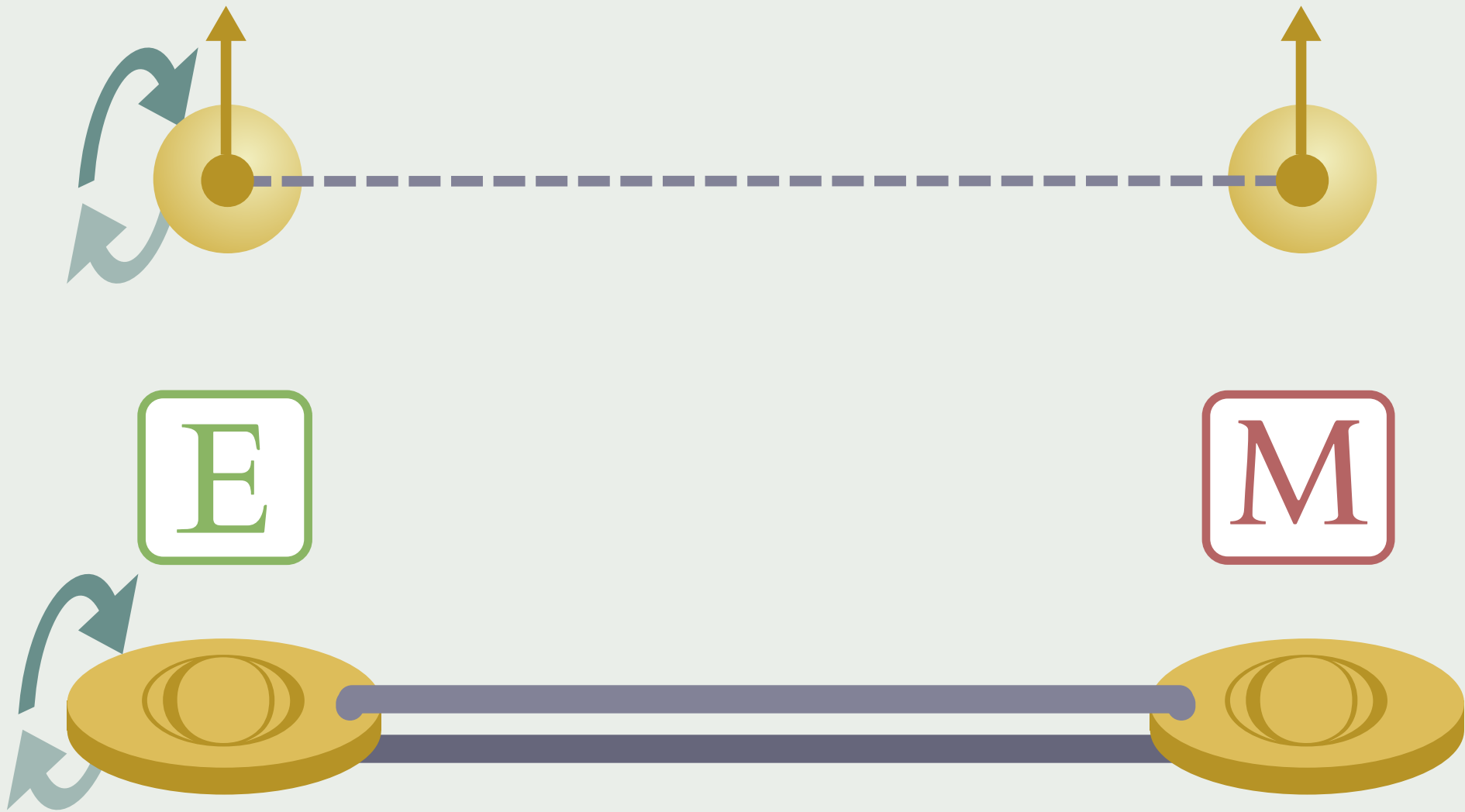
*David Wakeham*

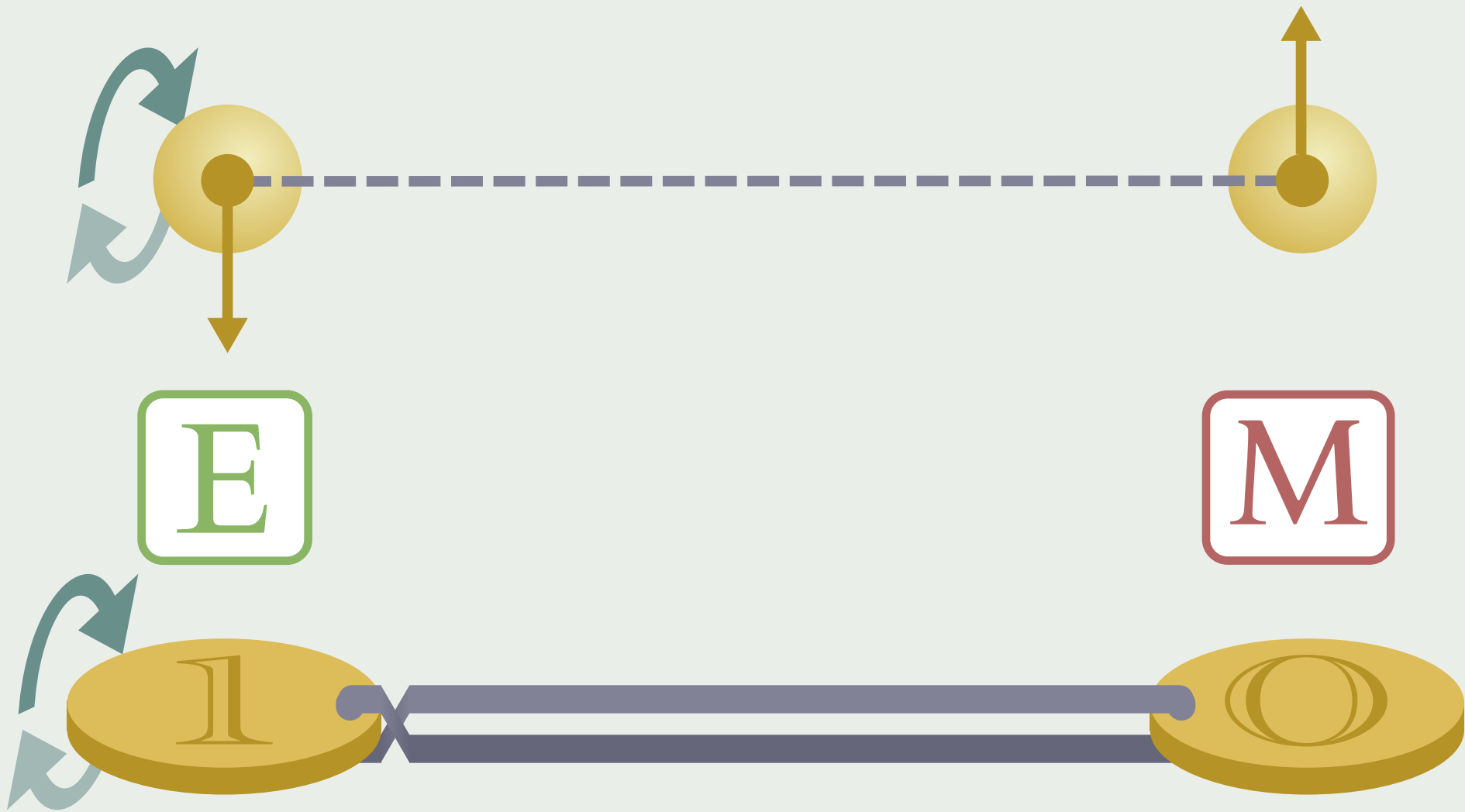
If the links didn't snap, you could

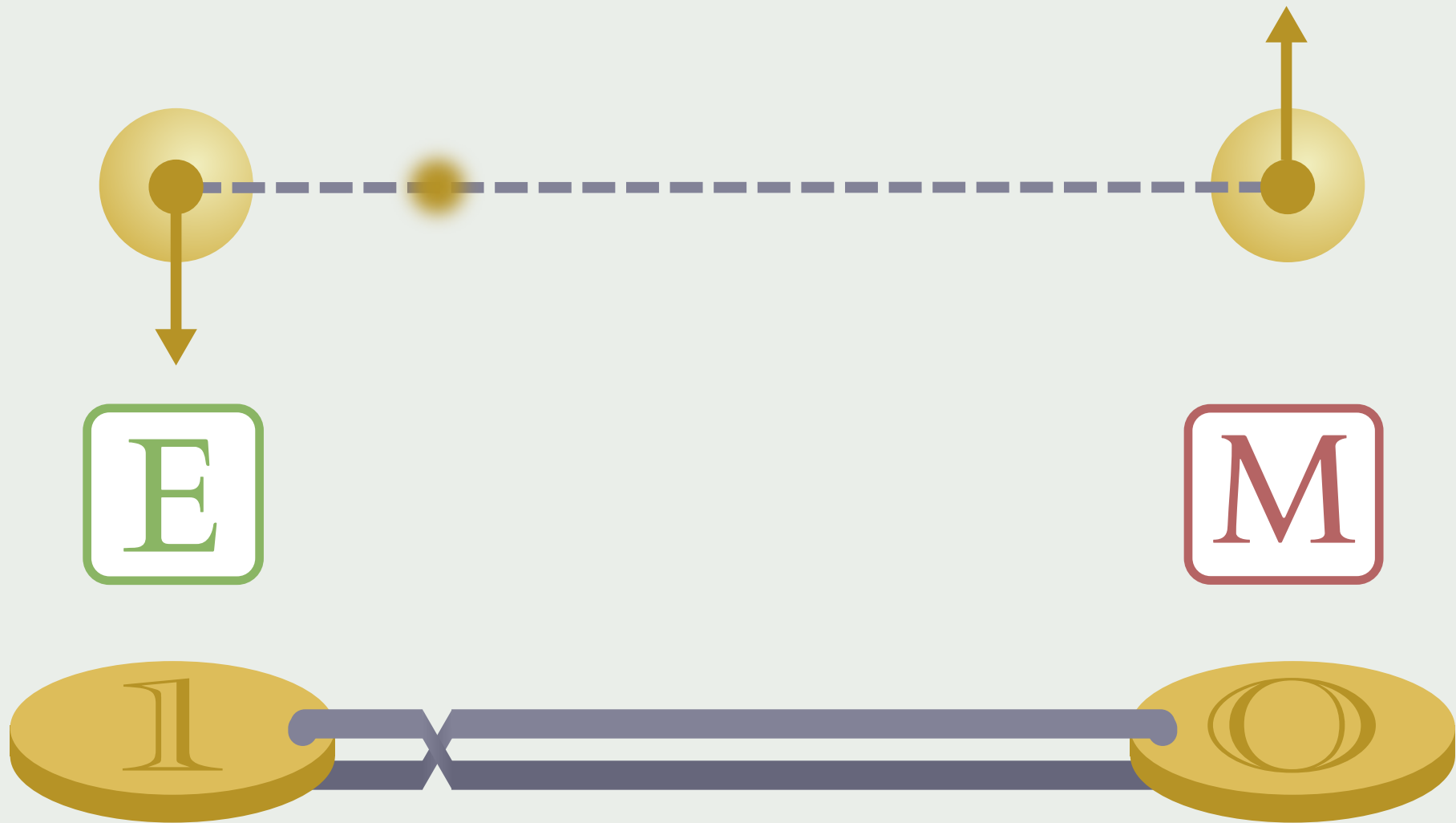
If the links didn't snap, you could  
use them to **send messages**.

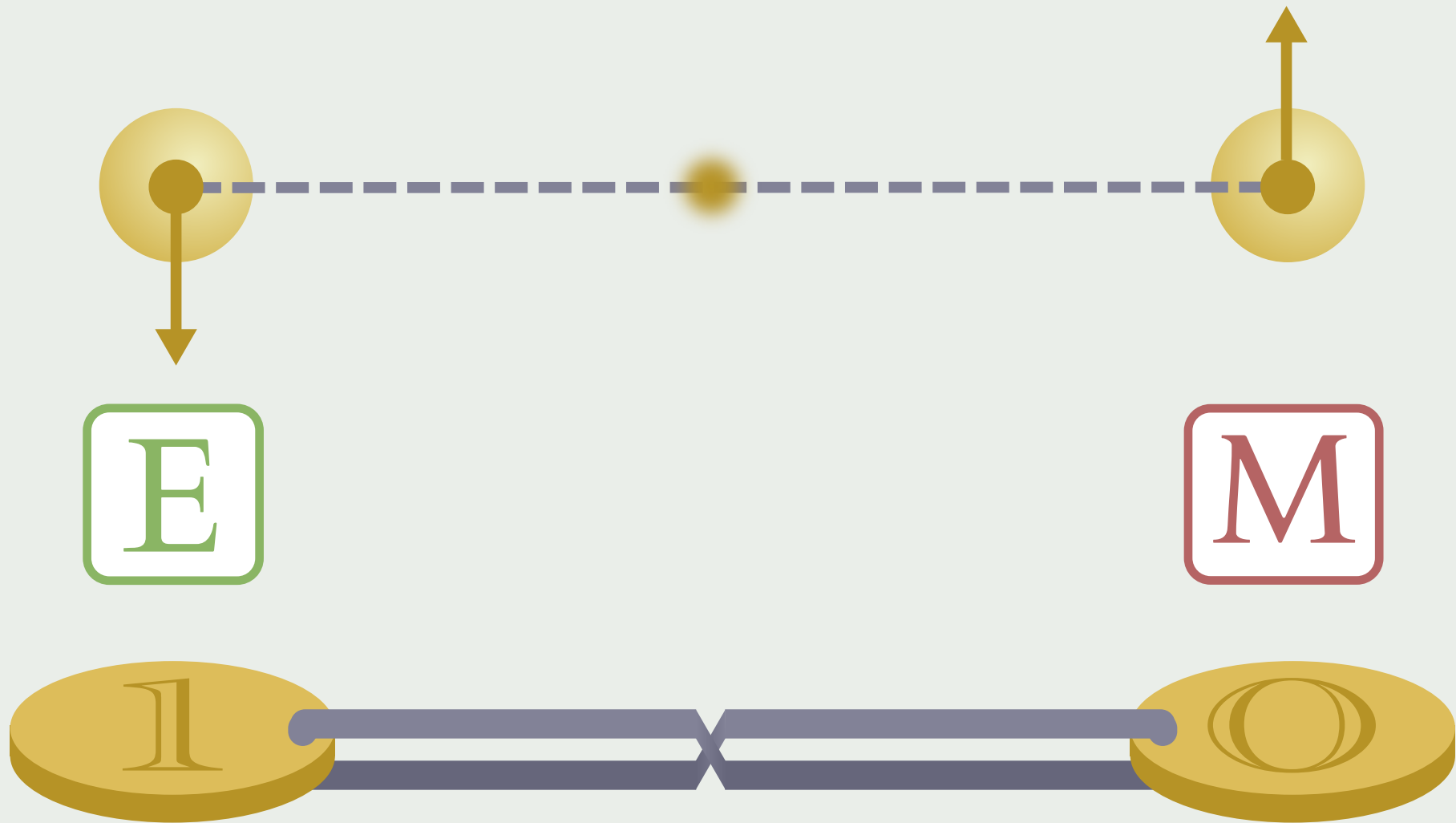


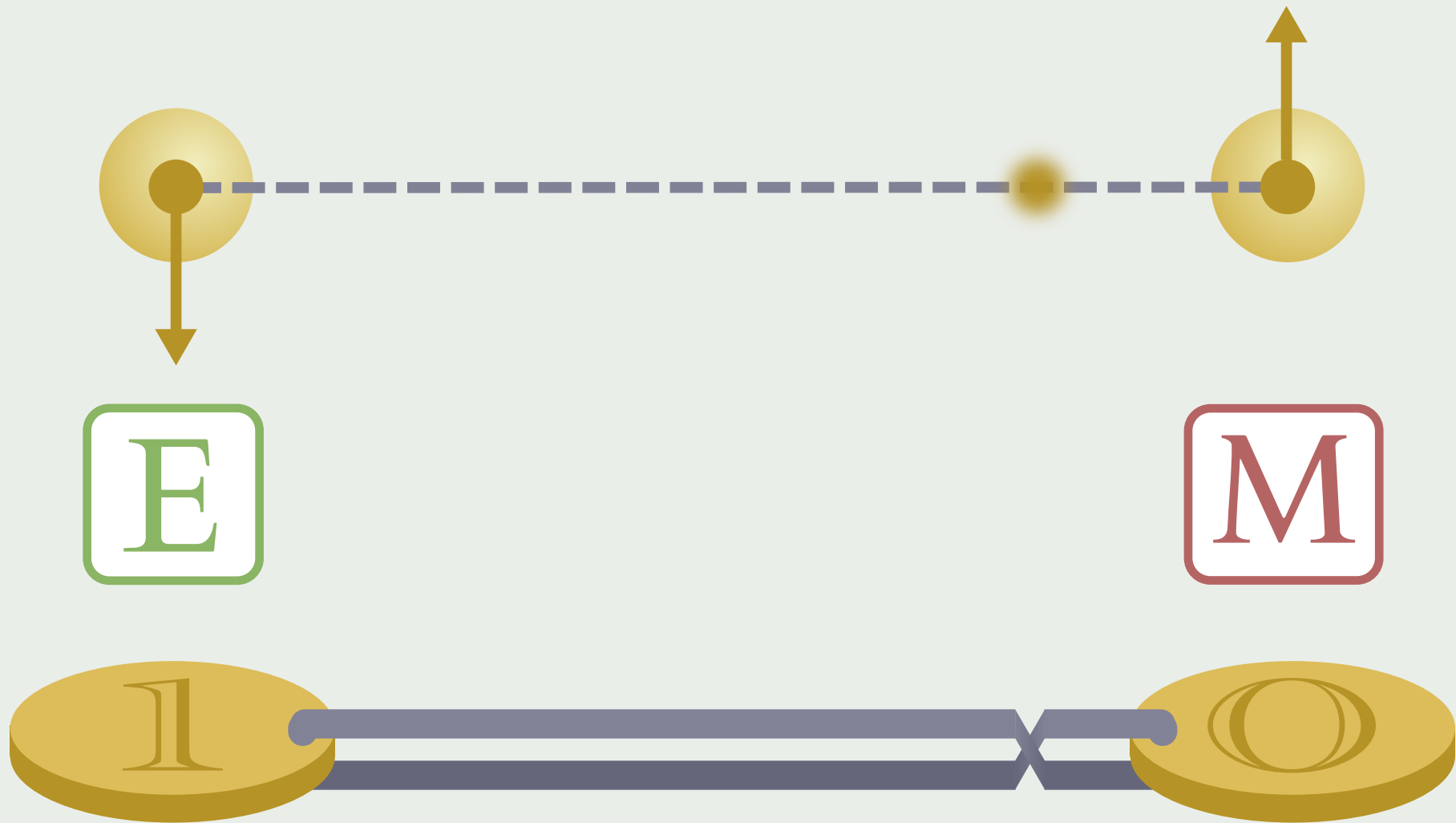














Entanglement, wormholes, and all that

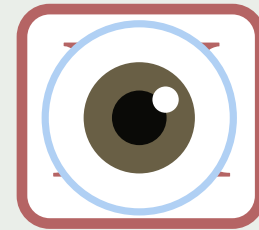
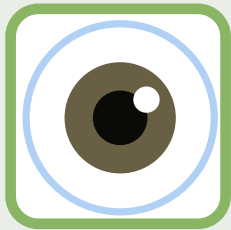
*David Wakeham*

No message sending allowed!



No message sending allowed!  
But E/M can learn outcome **simultaneously**.







Entanglement, wormholes, and all that

*David Wakeham*

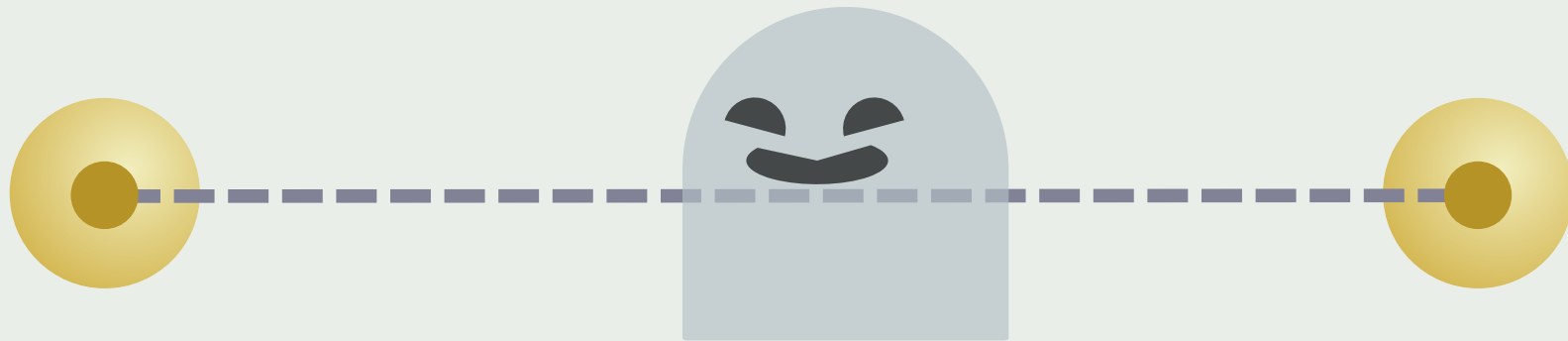
But this analogy fails in one key way:

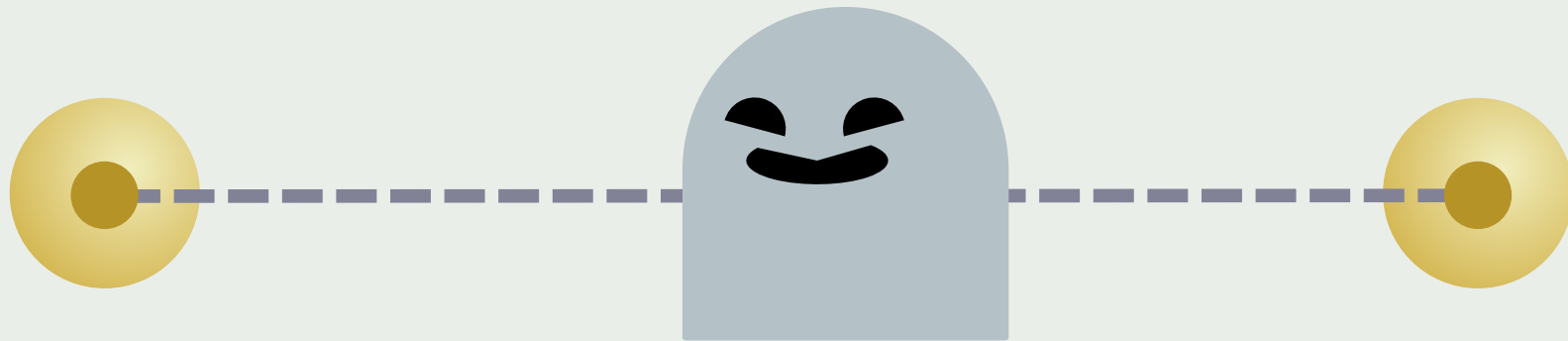
But this analogy fails in one key way:  
**nothing** connects the spins. It's spooky!

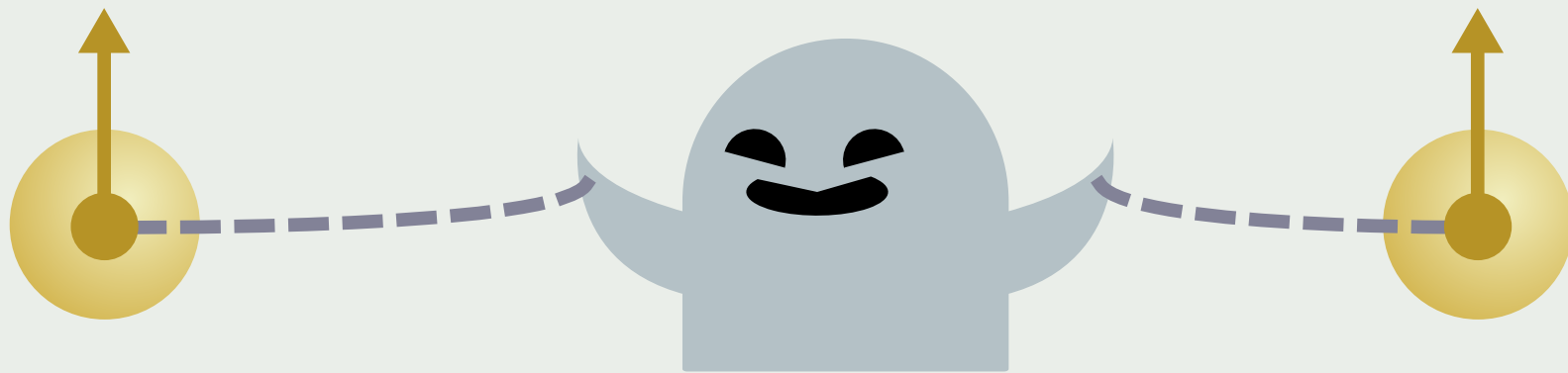










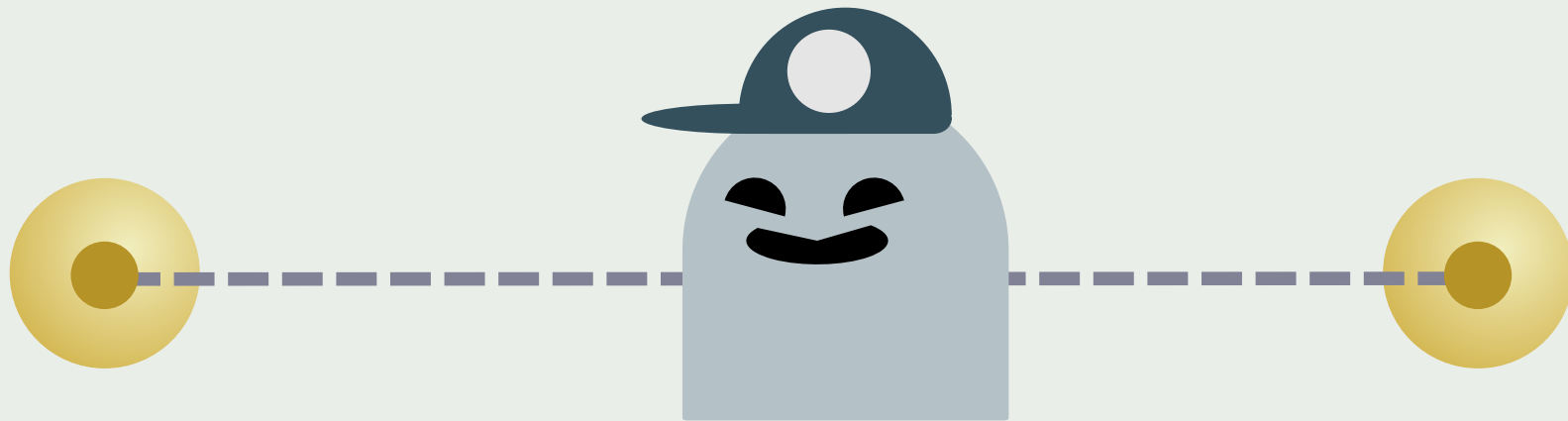


Entanglement, wormholes, and all that

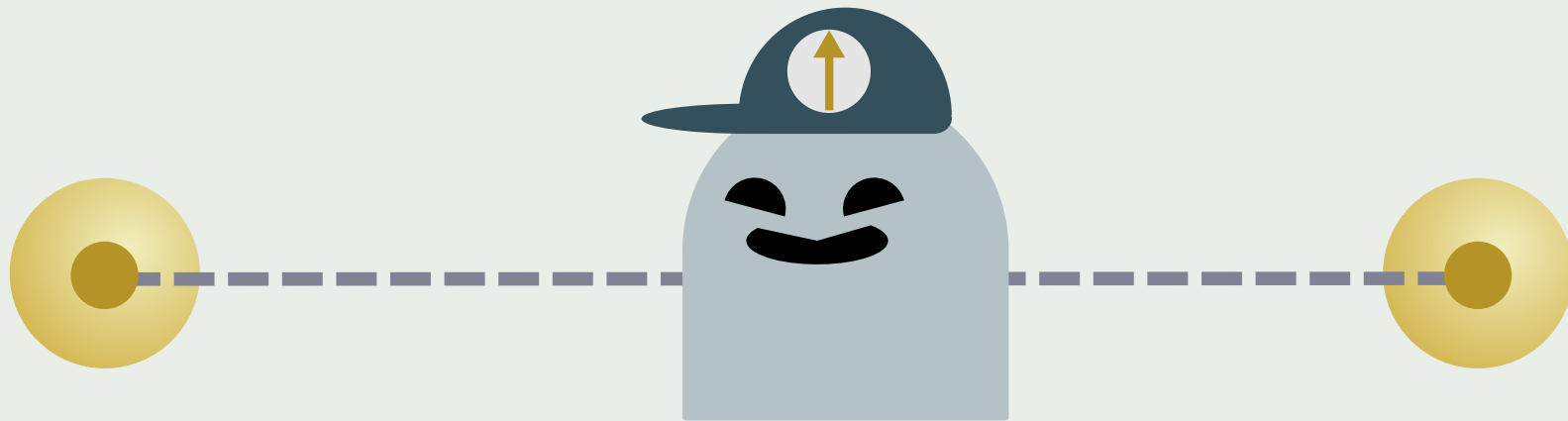
*David Wakeham*

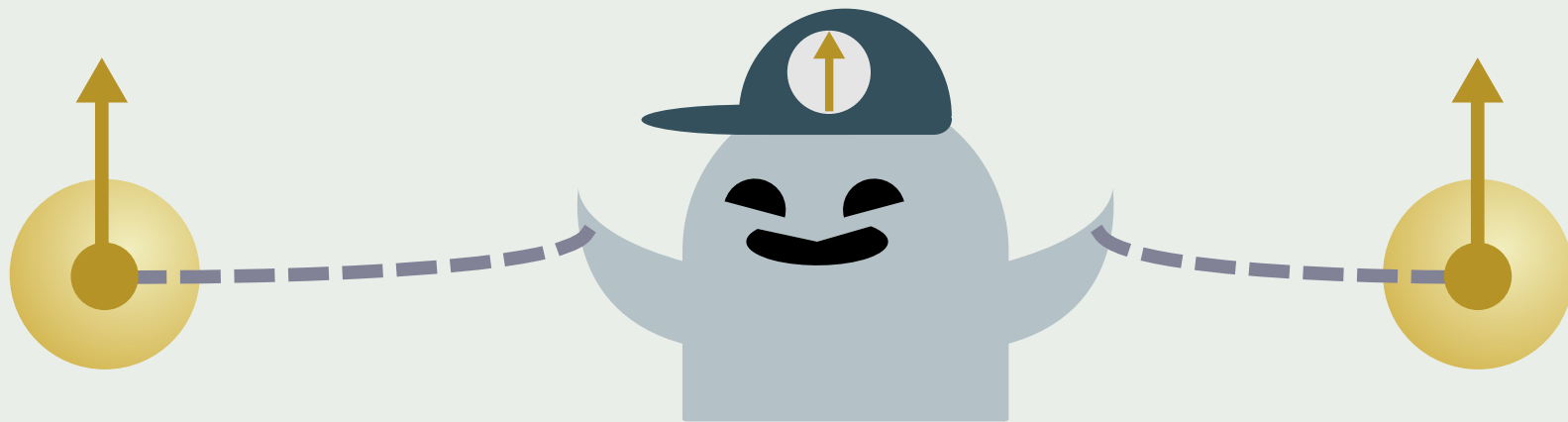
Einstein said: God doesn't play dice!

Einstein said: God doesn't play dice!  
He thought the ghost was a **hidden variable**.









Entanglement, wormholes, and all that

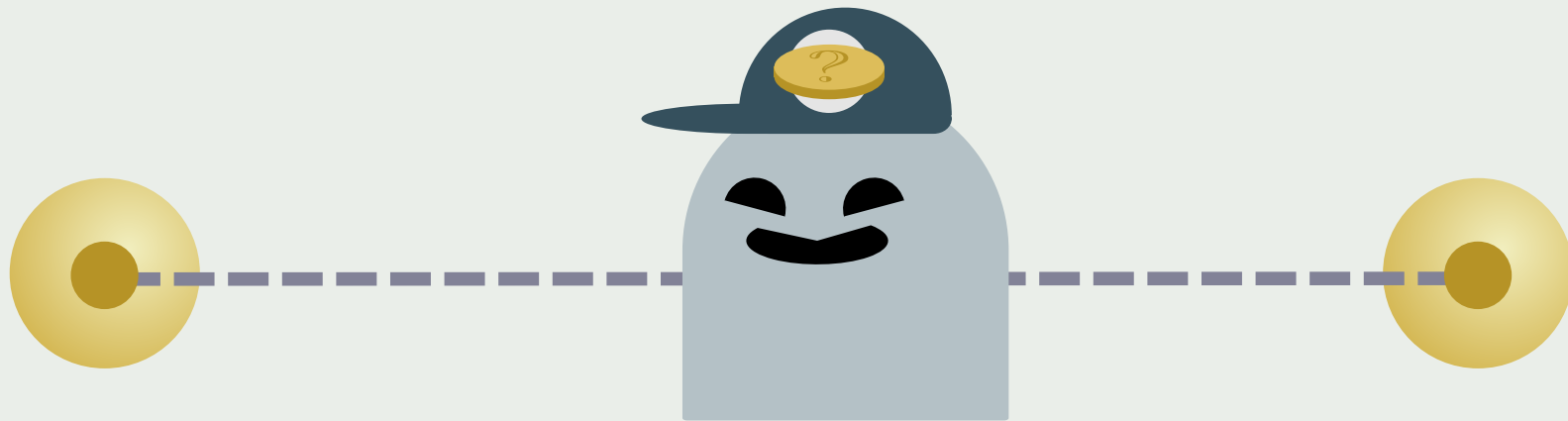
*David Wakeham*

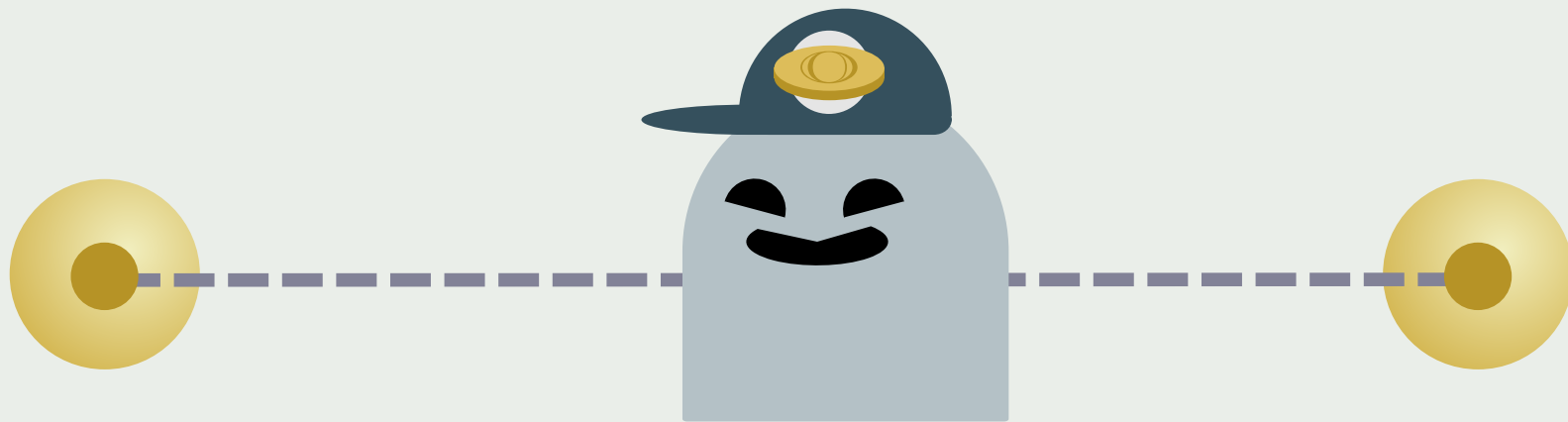
John Bell proved Einstein wrong.

John Bell proved Einstein wrong.  
If there is a ghost, it **flips a coin**

John Bell proved Einstein wrong.

If there is a ghost, it **flips a coin**  
and sends the outcomes **faster than light**.

















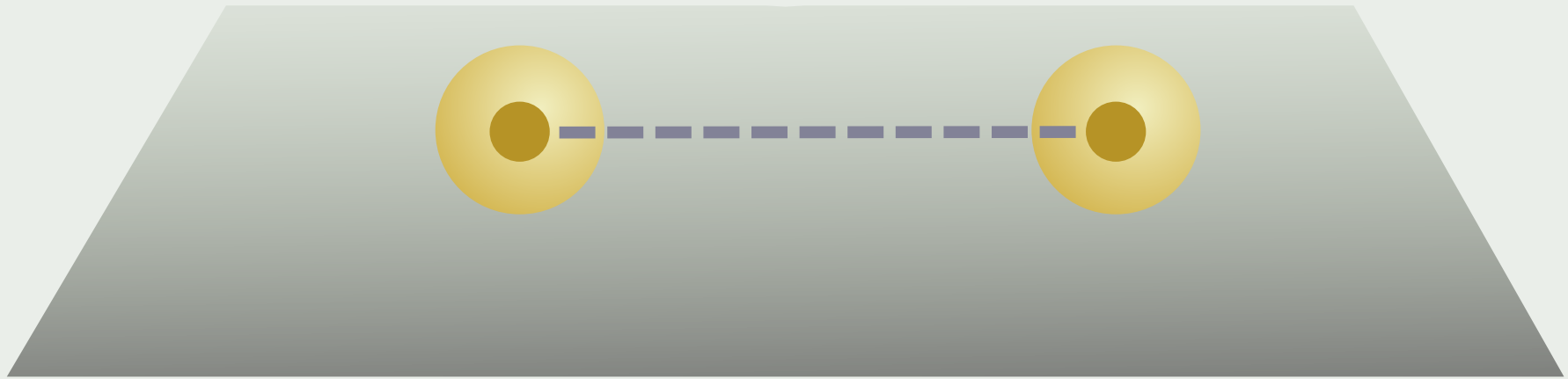
Entanglement, wormholes, and all that

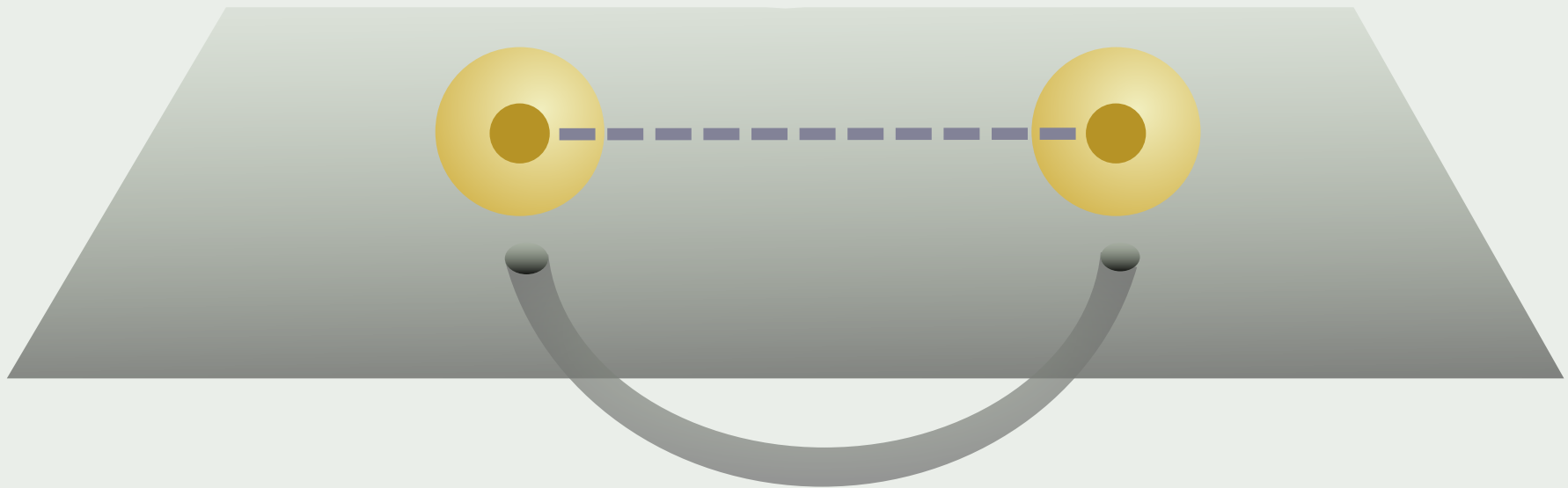
*David Wakeham*

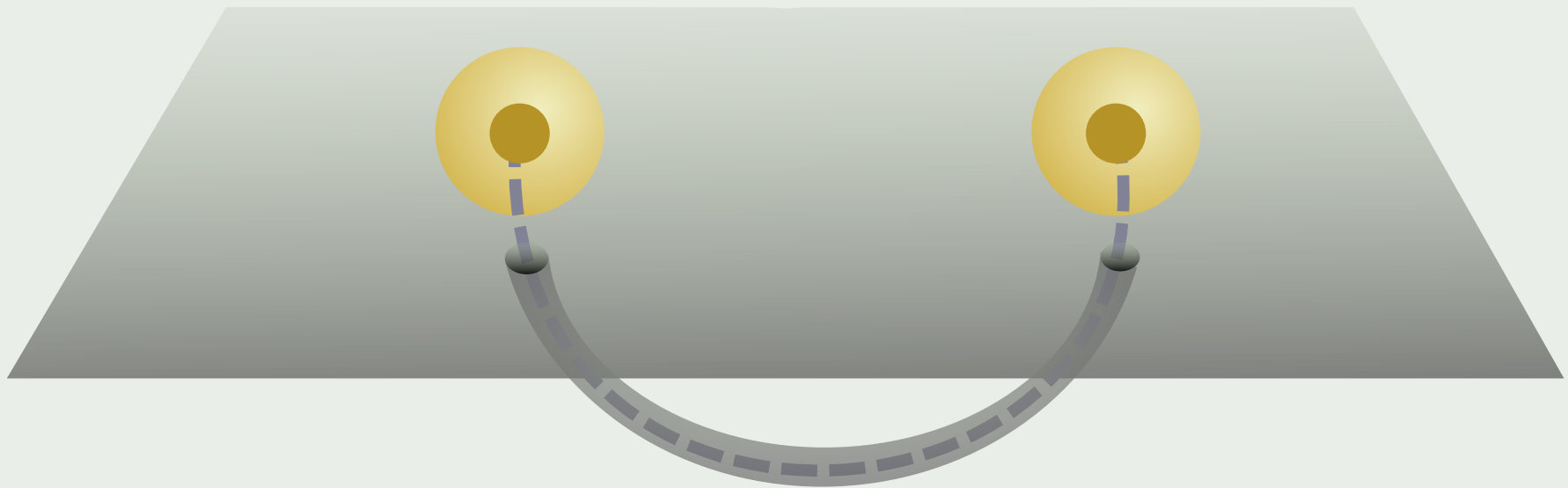
There is a surprising solution to the puzzle

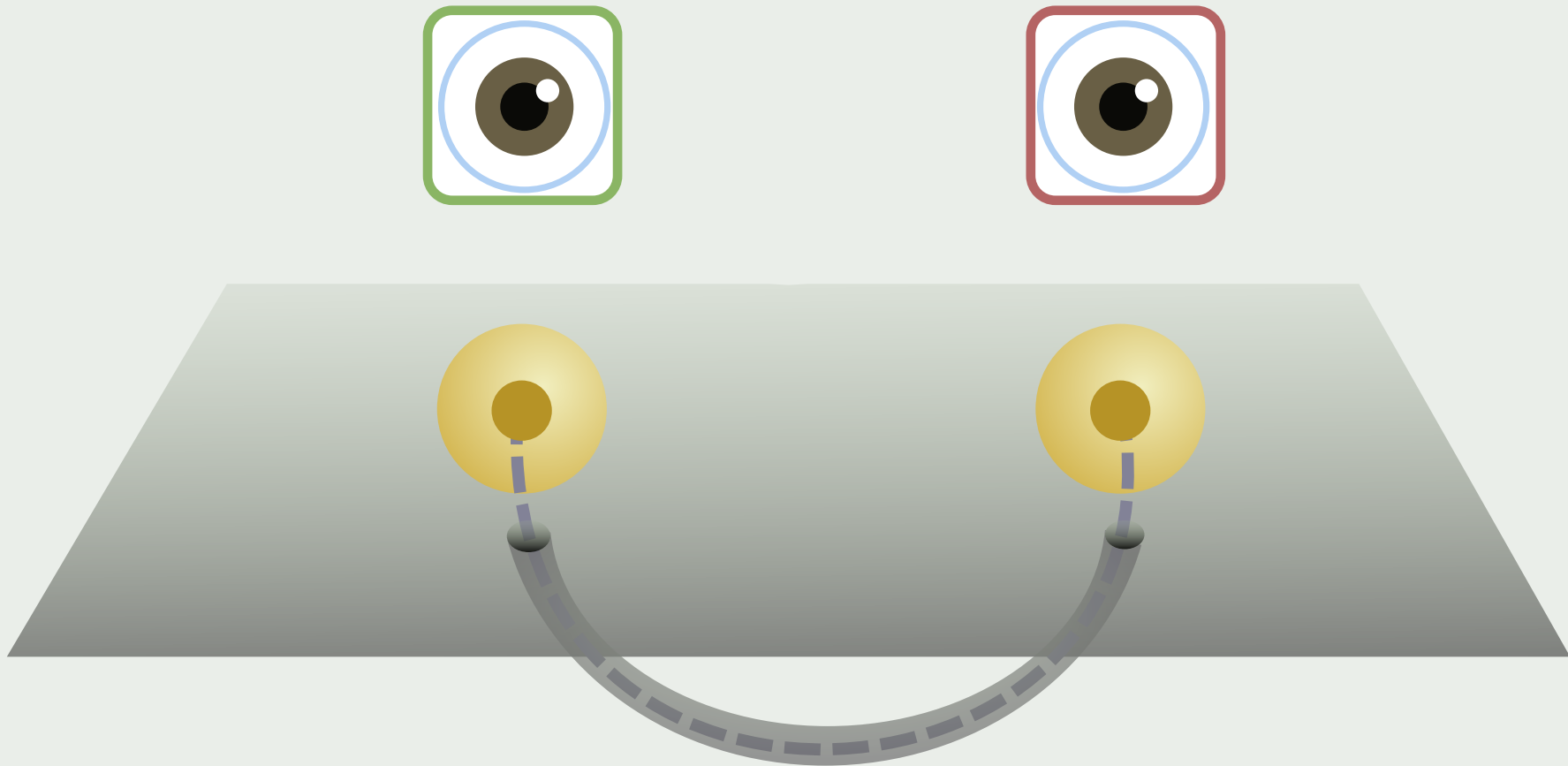
There is a surprising solution to the puzzle of spooky action at a distance: **wormholes**.

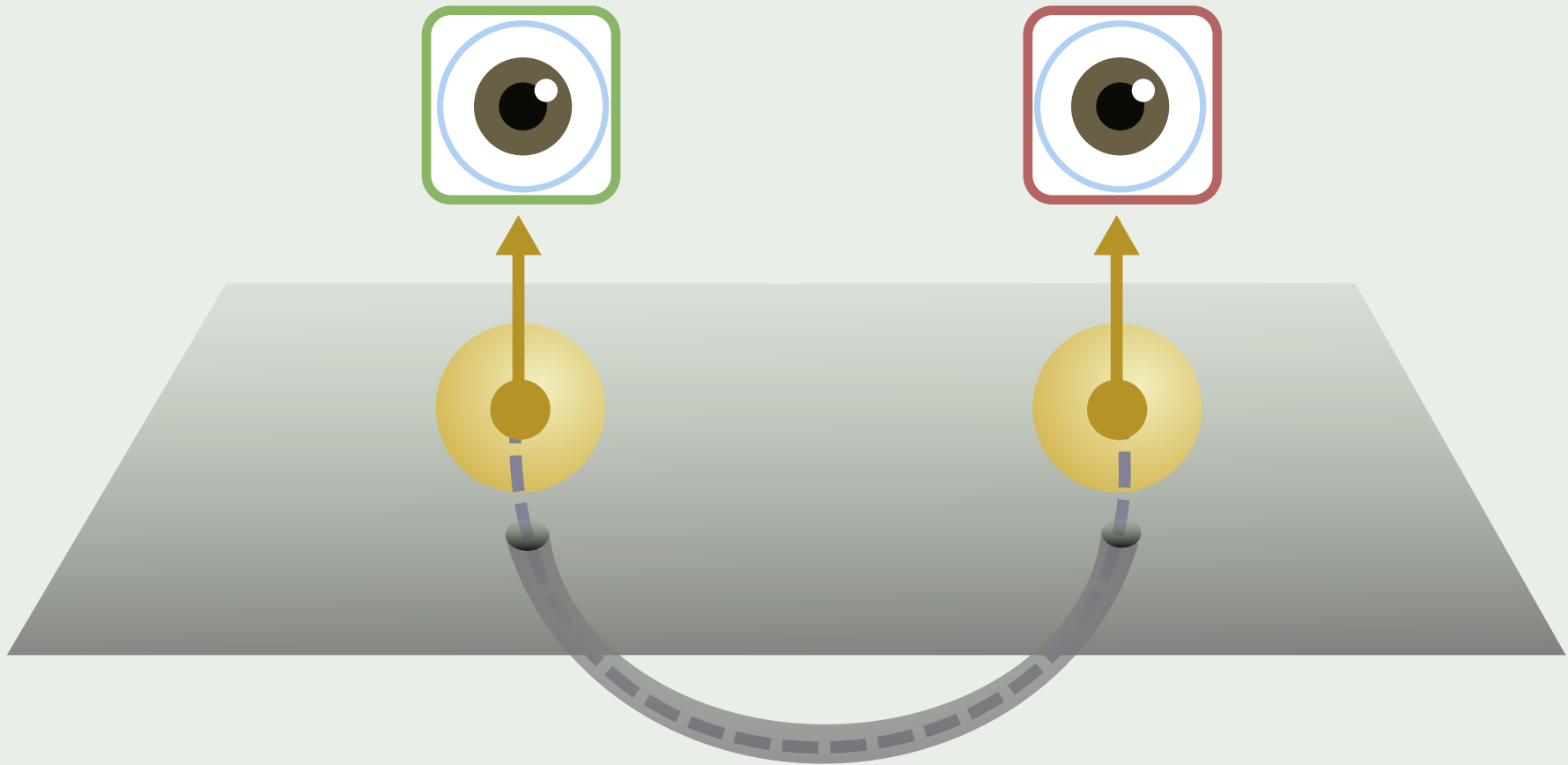


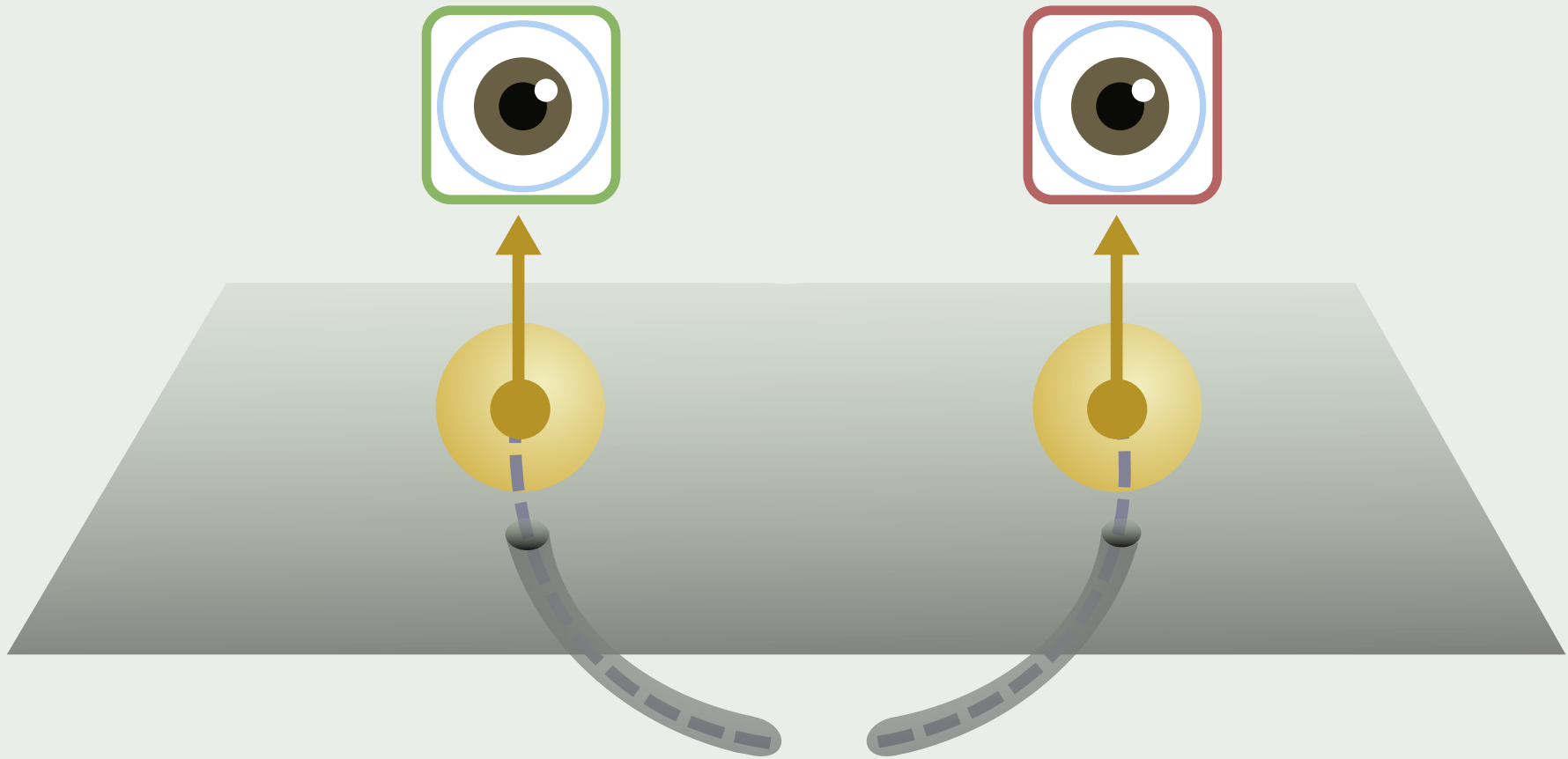


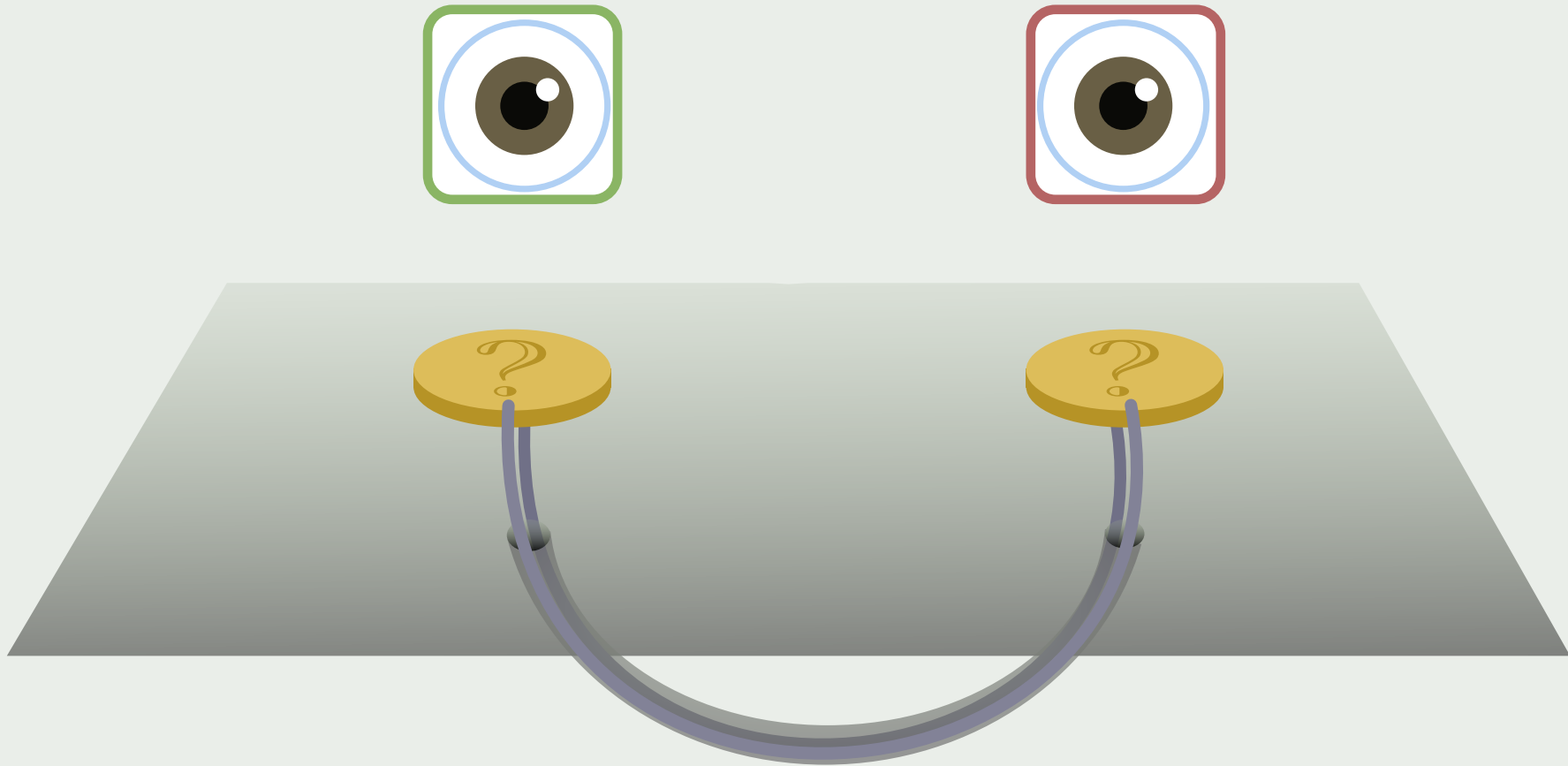


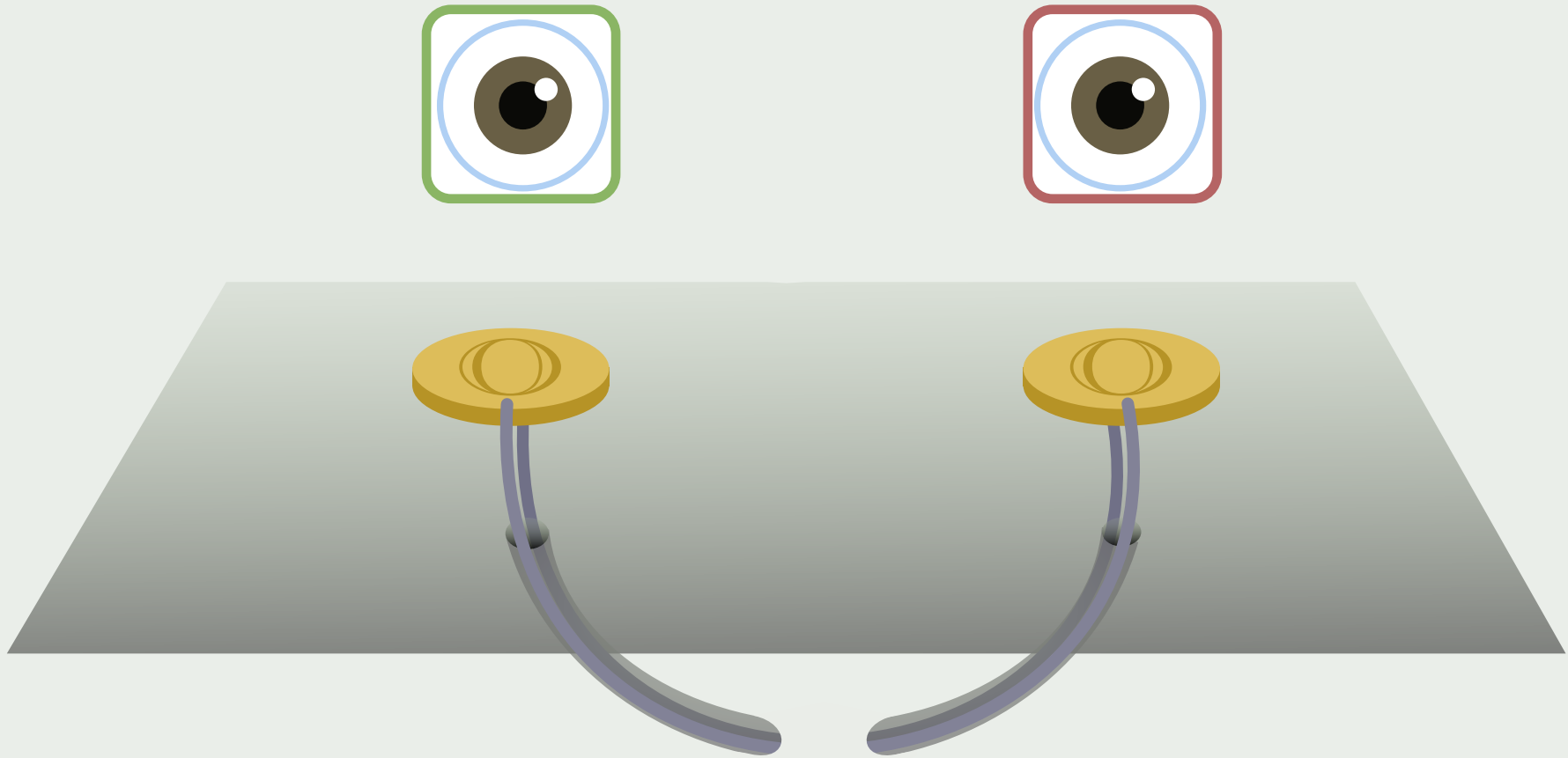












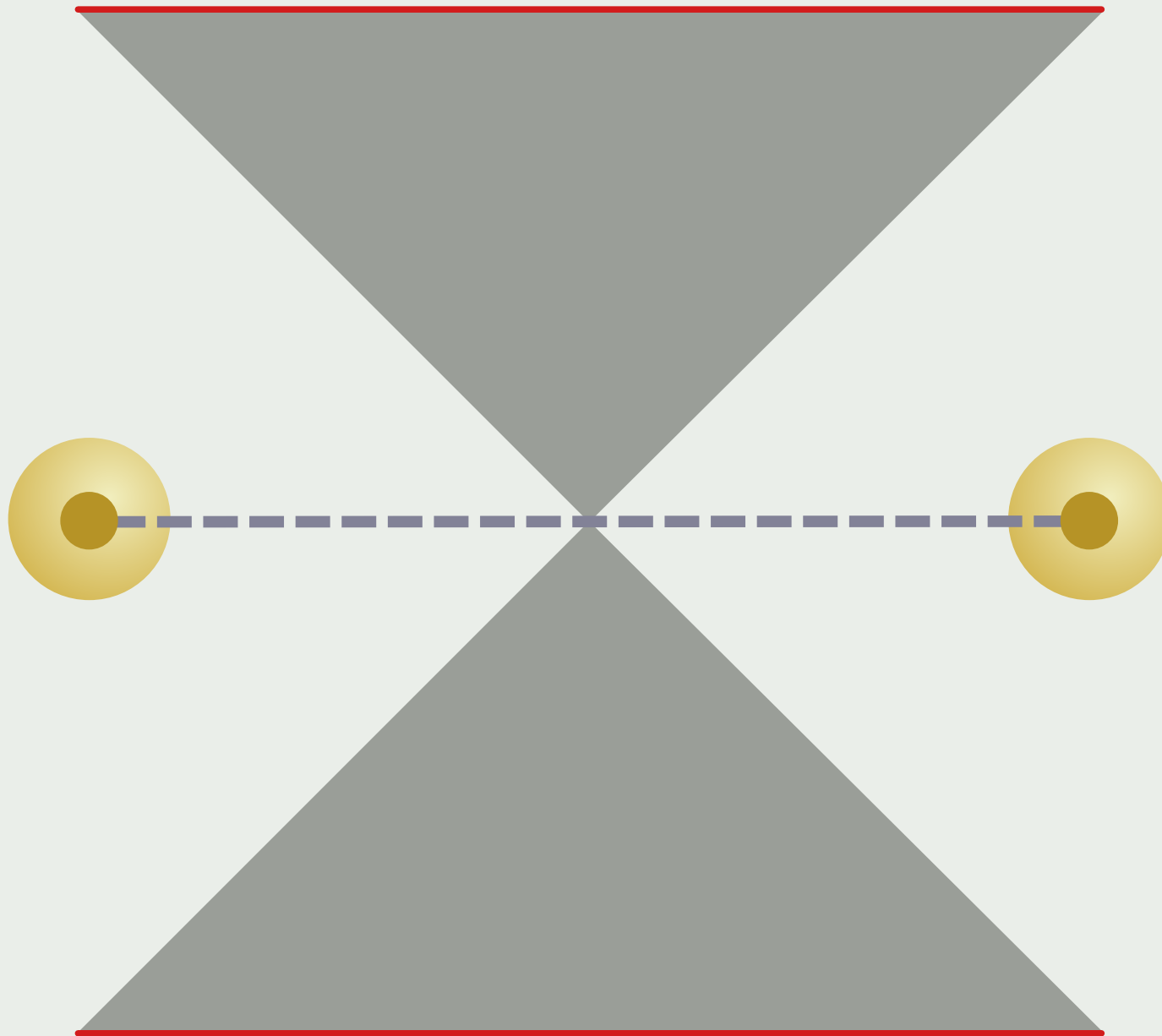


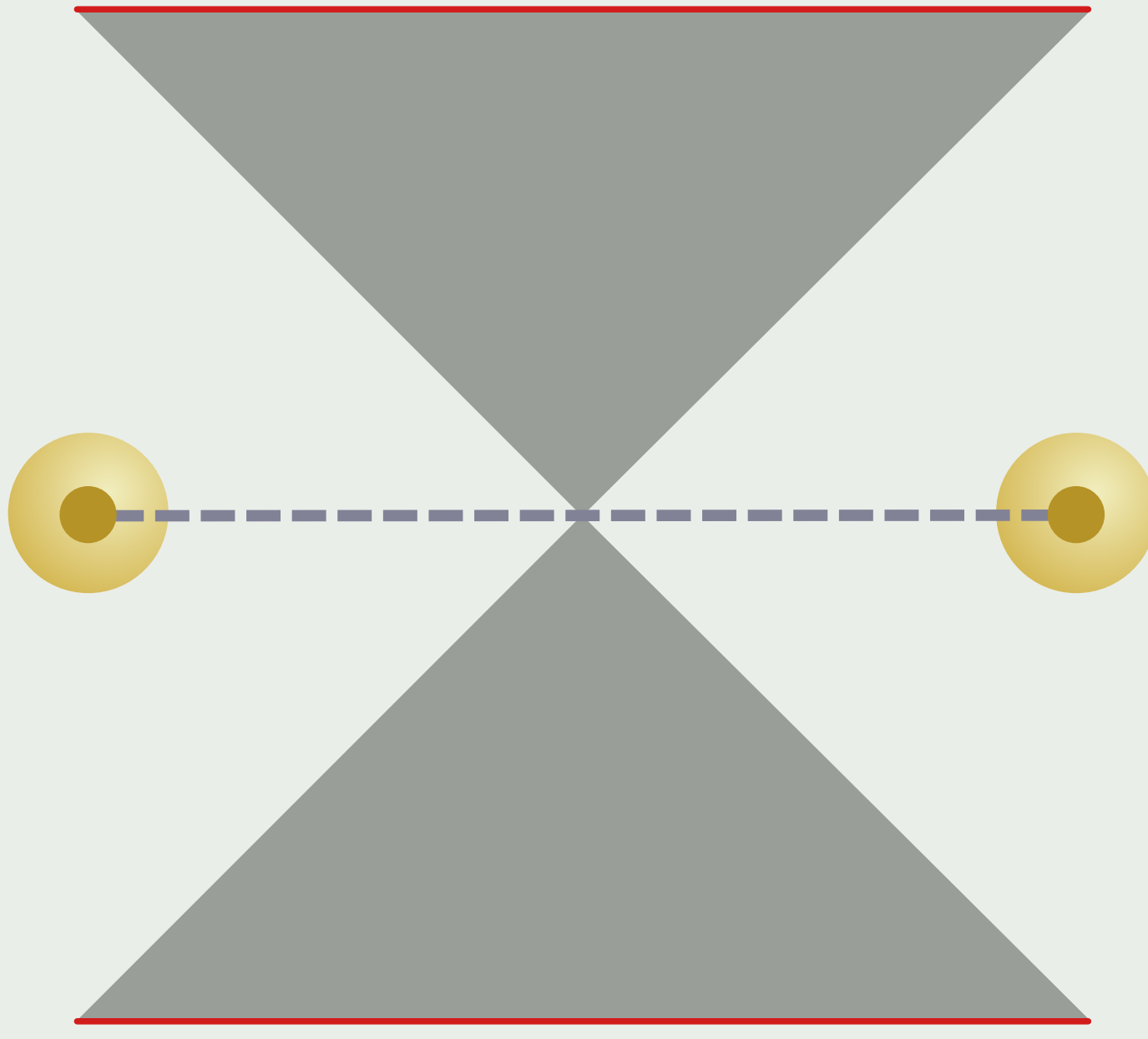
Entanglement, wormholes, and all that

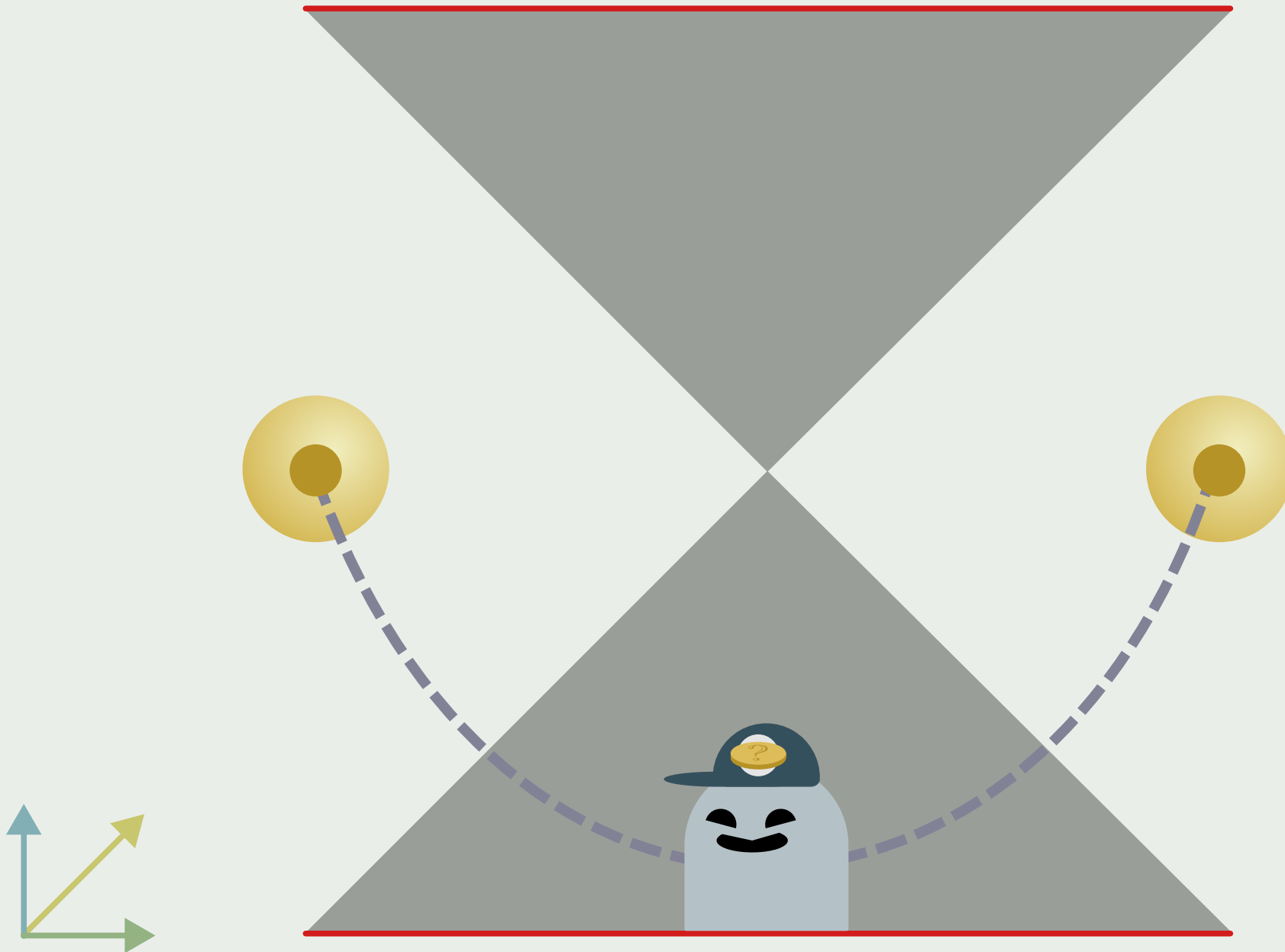
*David Wakeham*

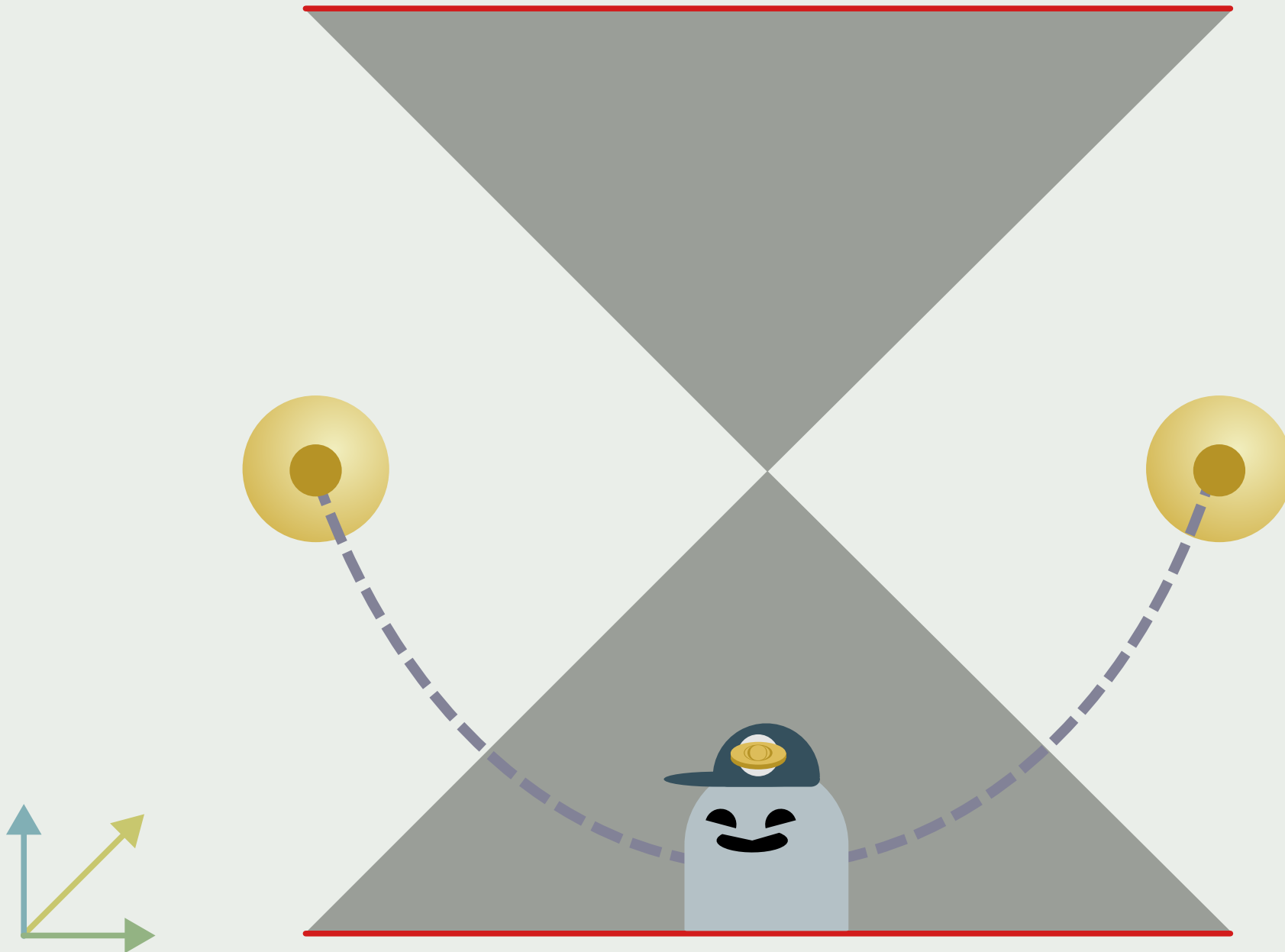
To understand what's going on better, we

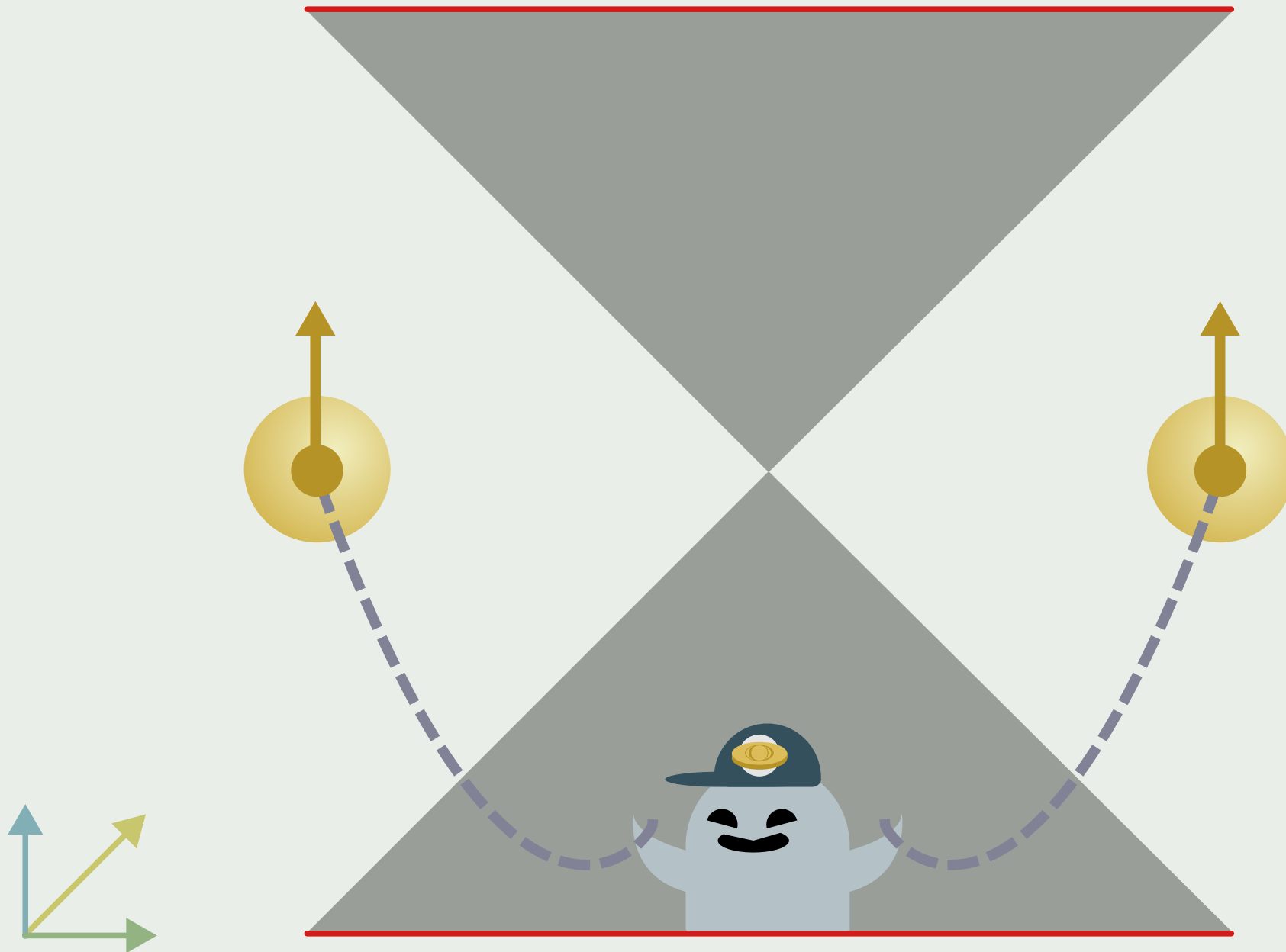
To understand what's going on better, we use a special diagram **invented by Penrose.**



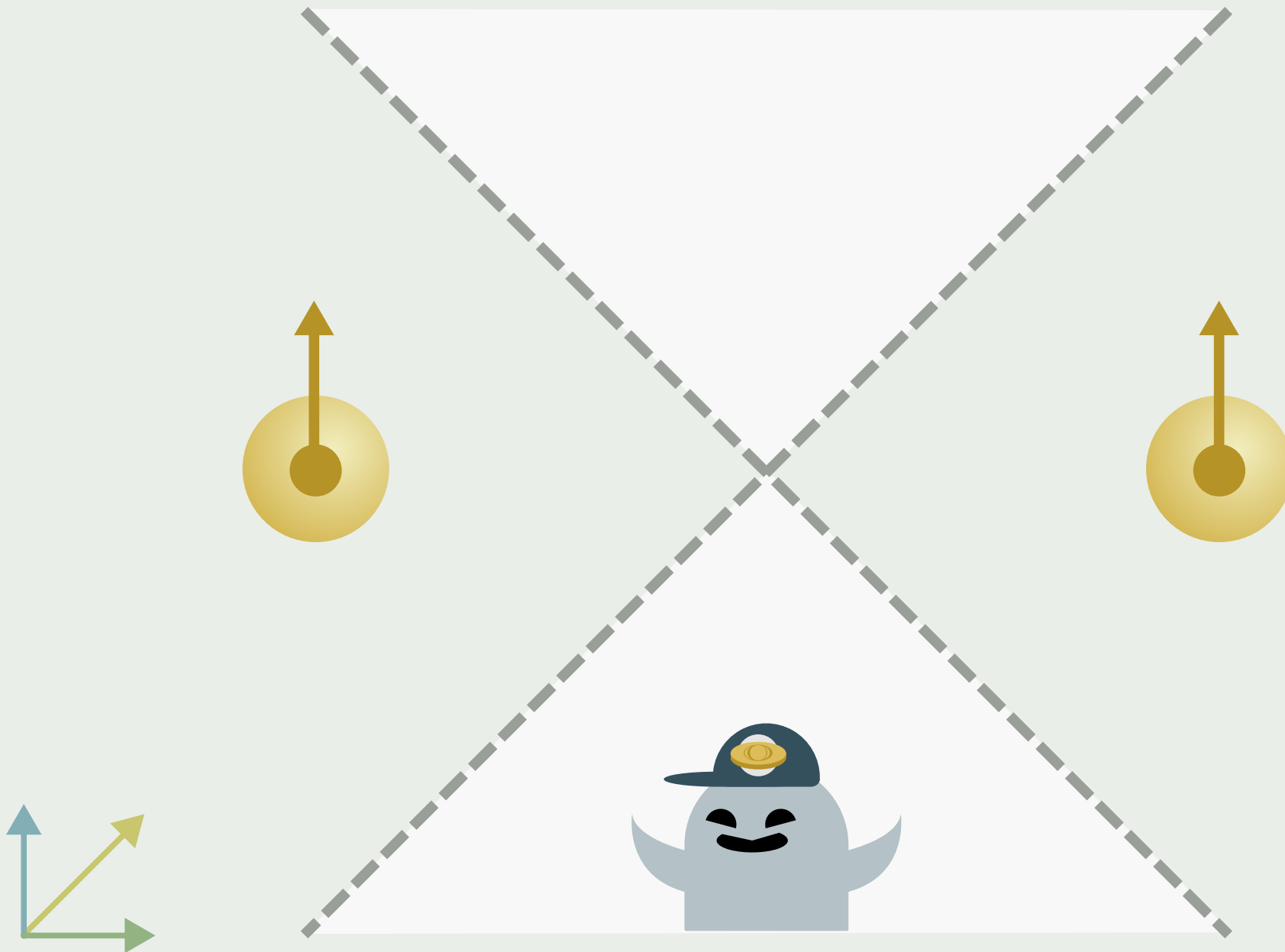


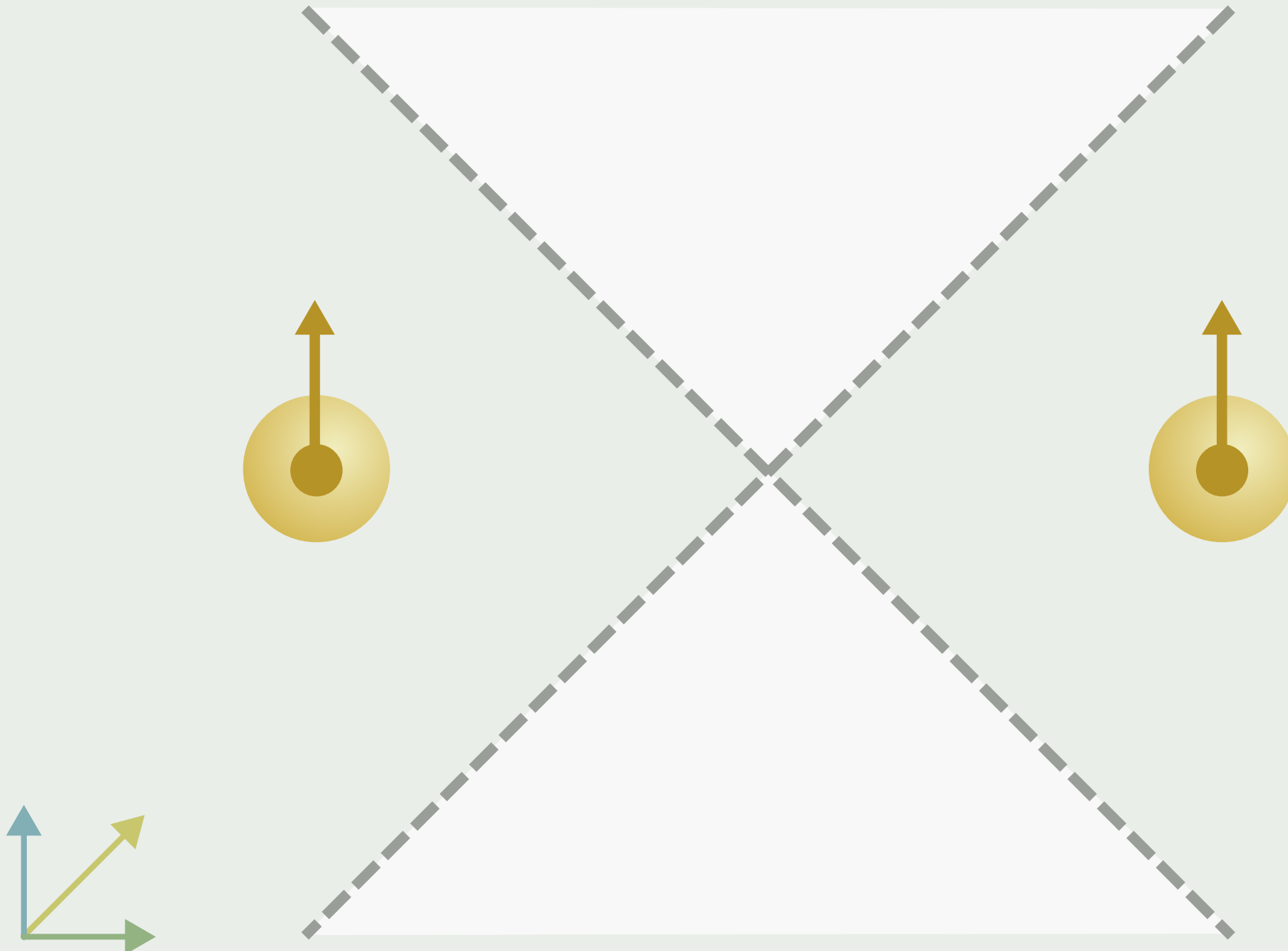


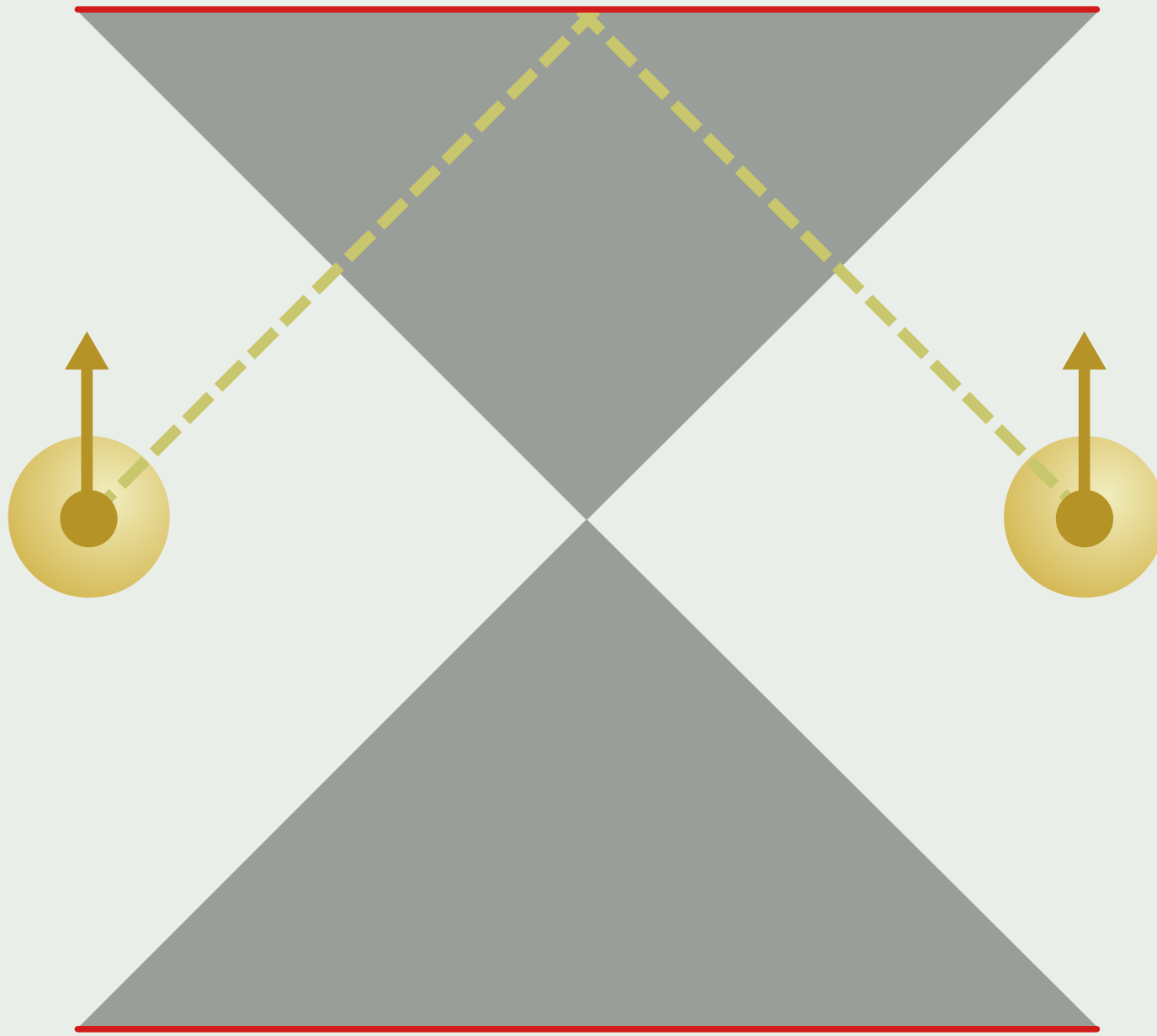


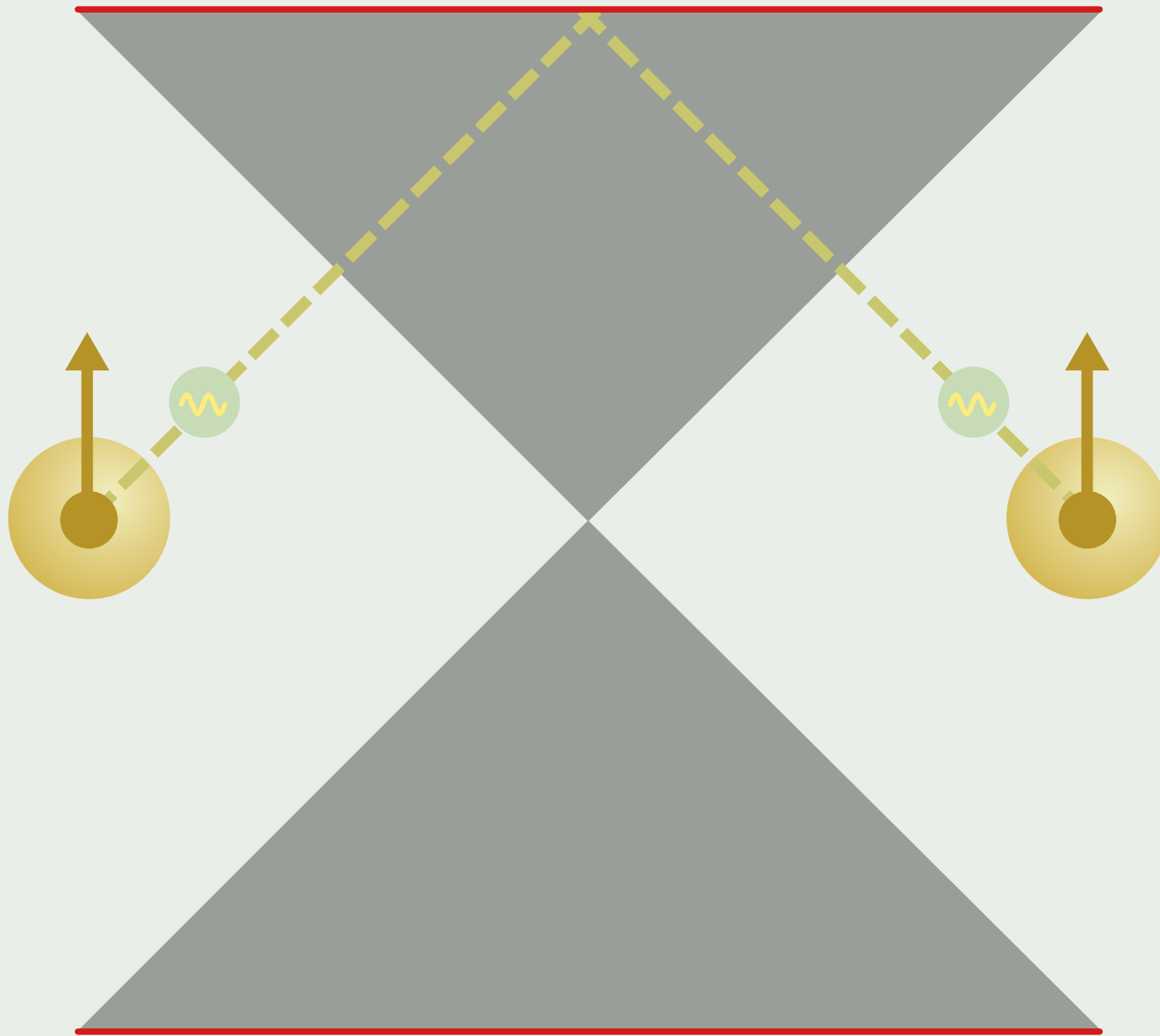


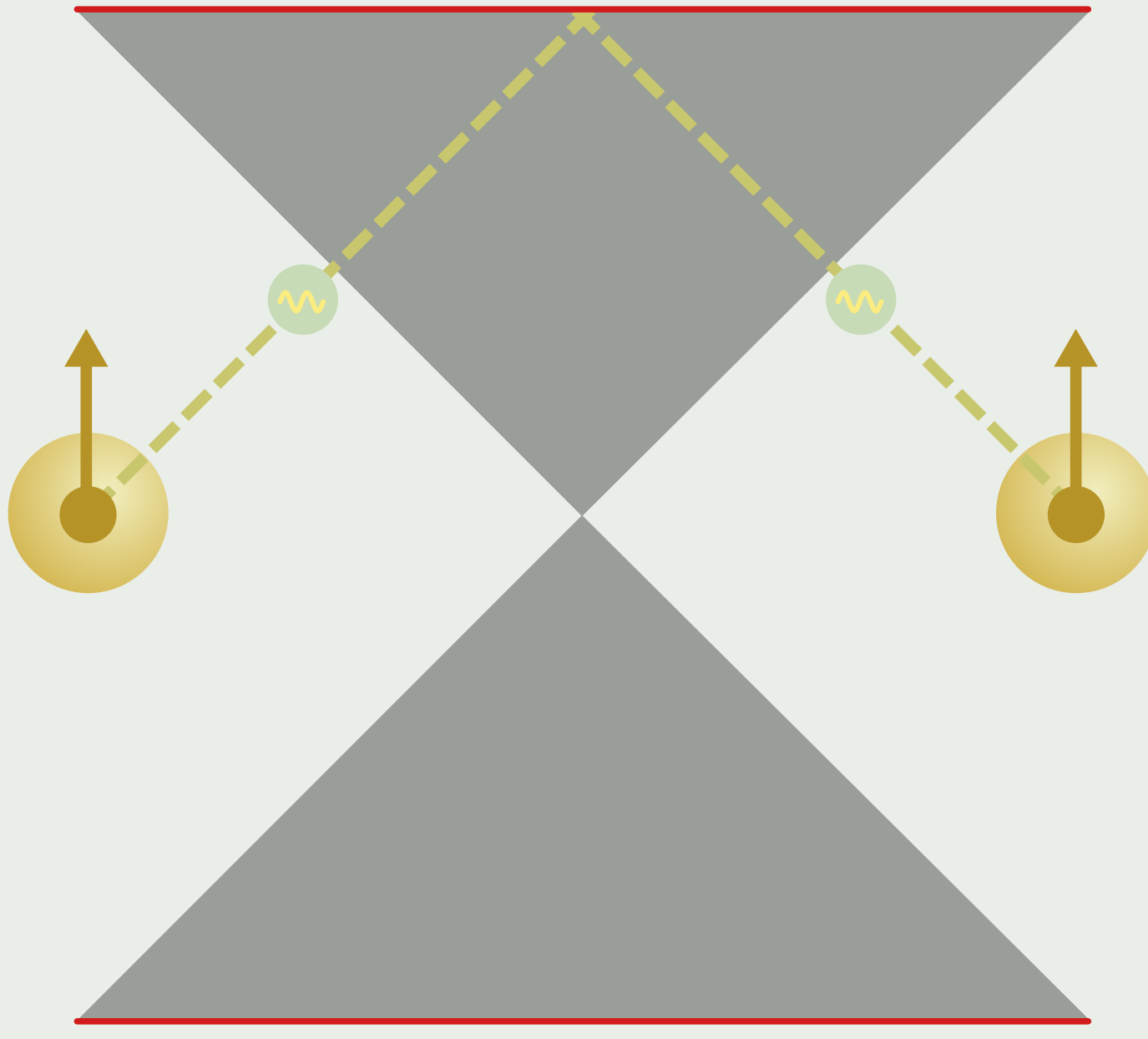


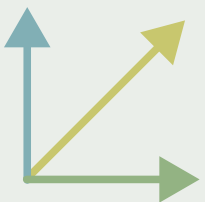
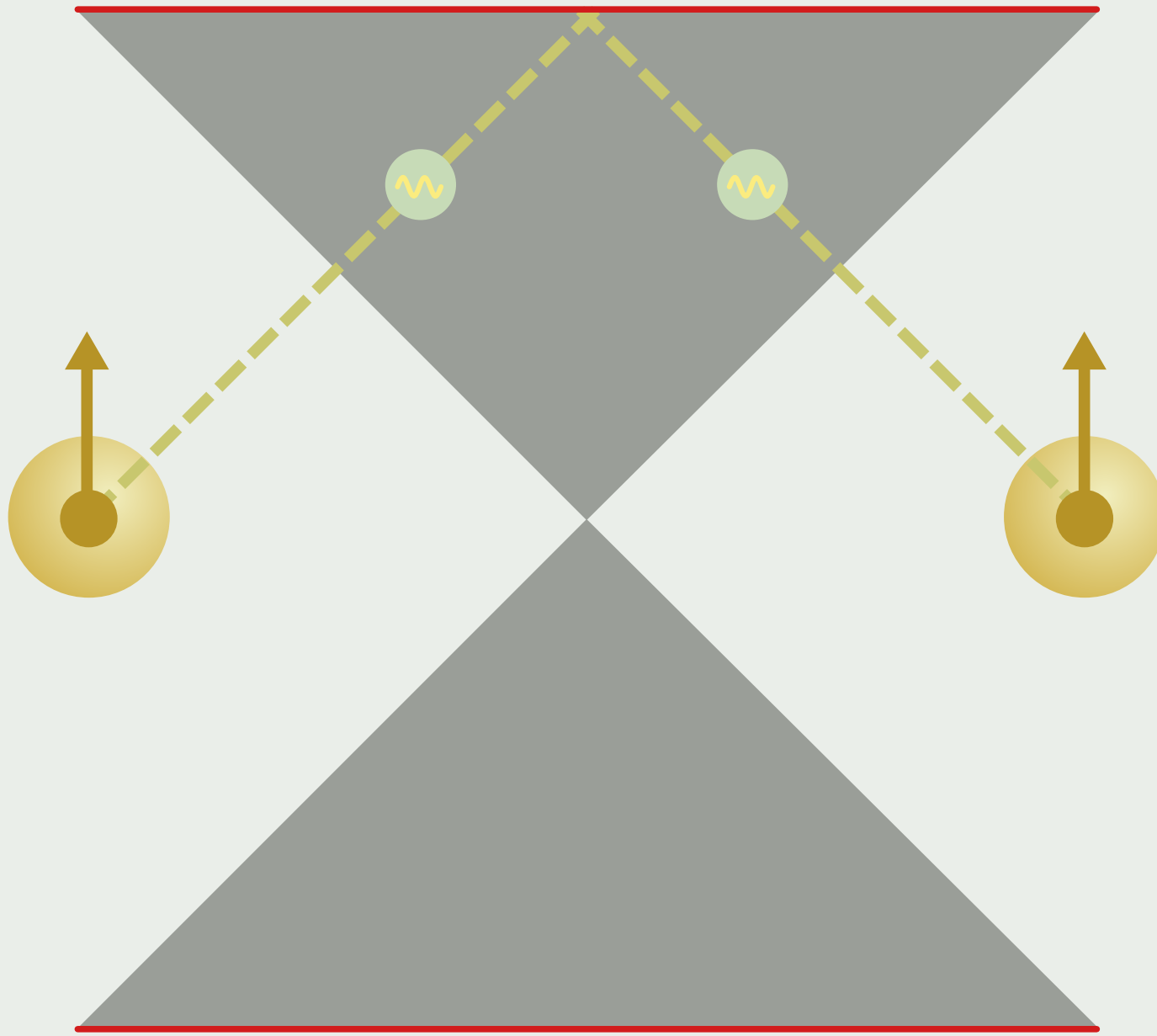


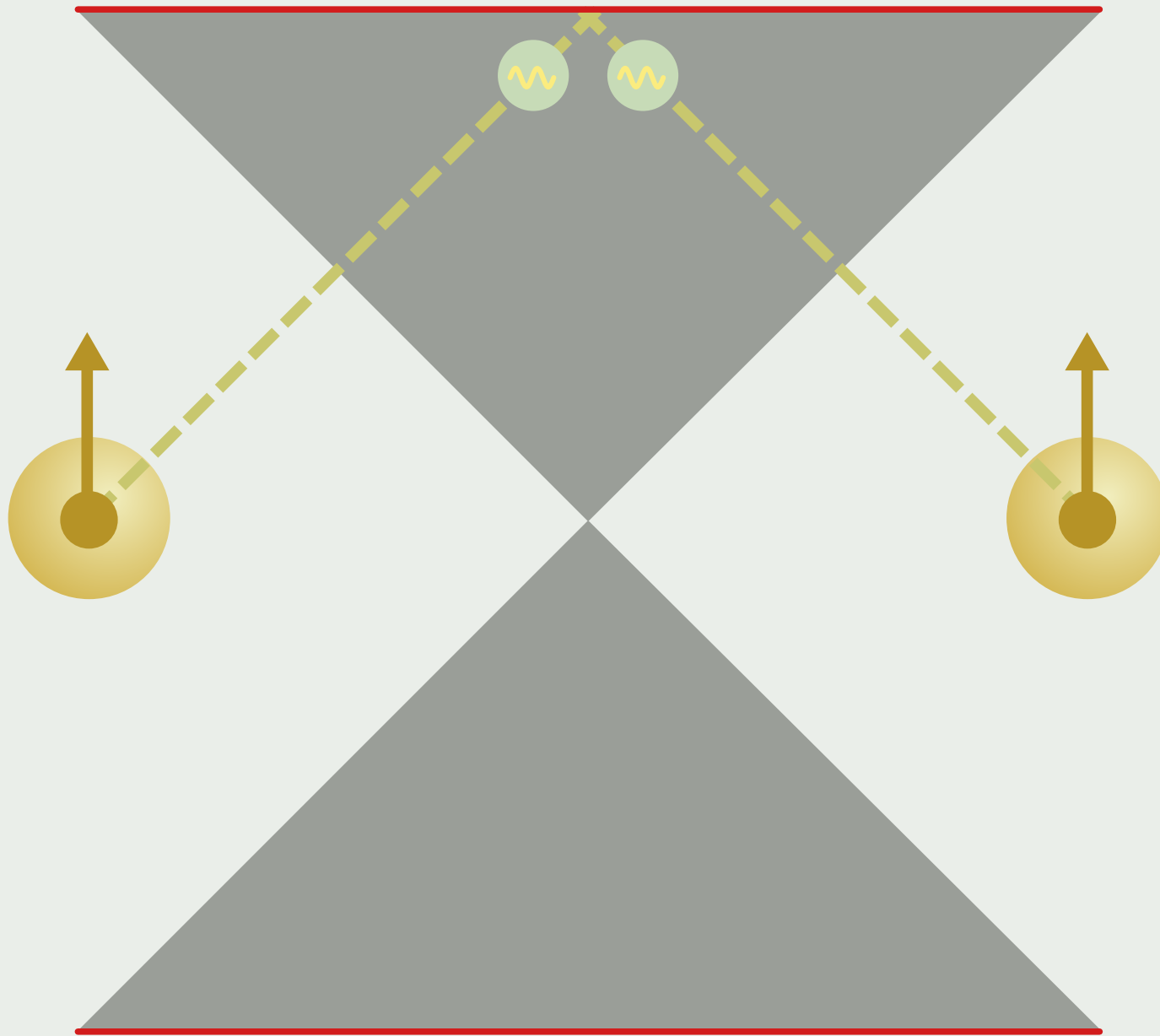


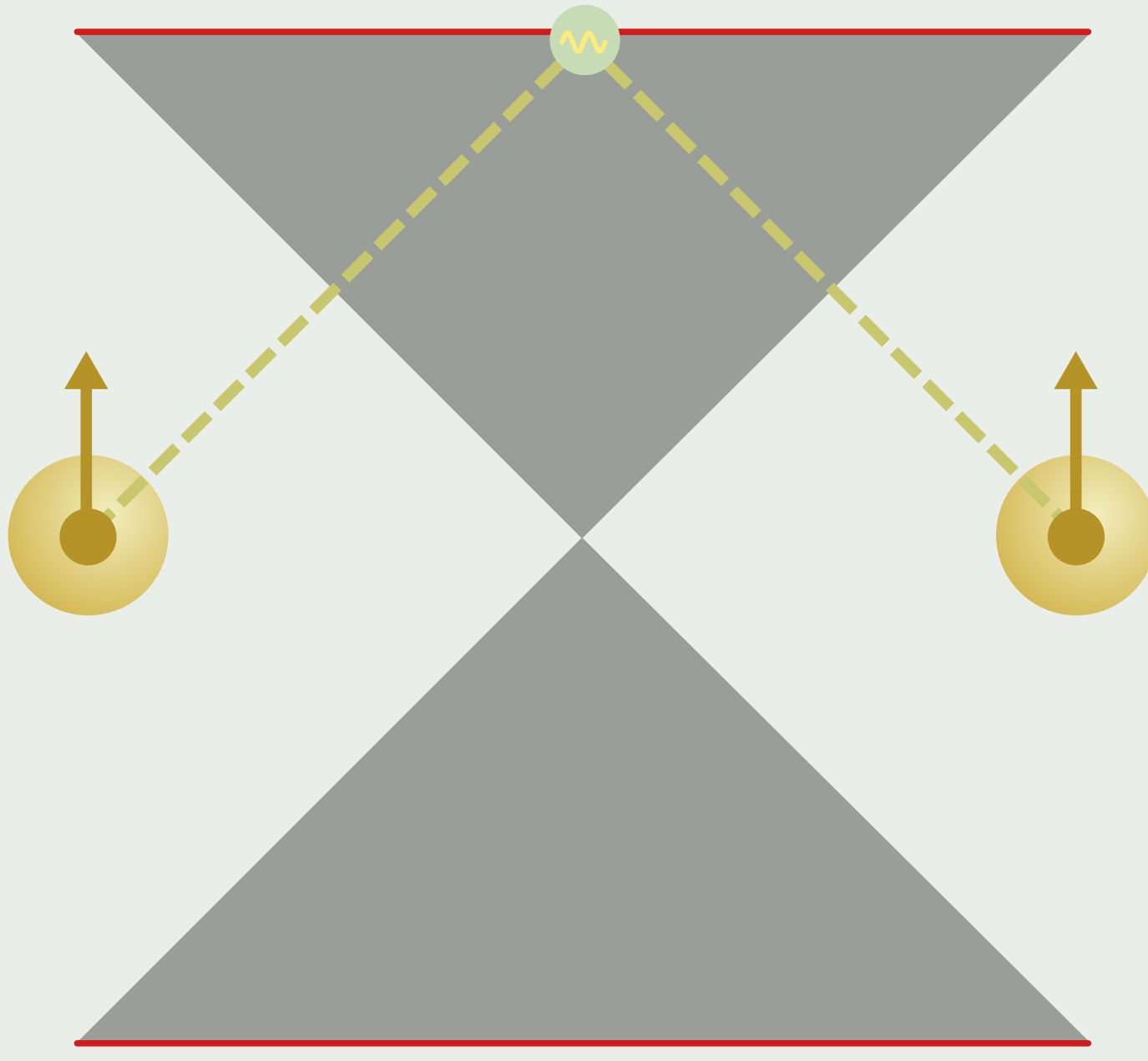














Entanglement, wormholes, and all that

*David Wakeham*

This conjectured equivalence is called

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**ER = EPR**

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**ER = EPR**  
for Einstein–Rosen and E–R–Podolsky.

Entanglement, wormholes, and all that

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You might wonder if there is a way

You might wonder if there is a way  
to explain **randomness** with wormholes.

