Dear Cheap Astronomy - Episode 003

Question 1:

Dear Cheap Astronomy - I was wondering, because, as I understand it, time stands still inside a black hole - the individual particles must be standing still as well. Does that mean the temperature of a black hole is zero Kelvin? Rene.

Hi Rene - Interesting problem. I'm not sure I have the answer, but here's what I think it is. Firstly, there's a relativistic context here. From our perspective, time stands still in a black hole - while from a frame of reference within the black hole, the remaining lifetime of the universe whizzes past outside in an instant. I don't know that we can say with confidence that time actually stops in a black hole - there might just be a huge time differential between what happens inside and what happens outside.

It is puzzling that the stages of a massive star's evolution into a neutron star involve ever increasing temperatures and densities. But then when the object hits a certain density, so that an event horizon is created around it, we have to assume the temperature suddenly plummets to zero Kelvin.

But you make a good point about the particles standing still in the black hole. Temperature is really an emergent property of the oscillatory motion of sub-atomic particles. A rise in temperature equates to atoms and ions and electrons vibrating faster. Hence you would expect that a state of zero particle motion must equate to a temperature of zero Kelvin.

So yes, you could certainly argue that, from the perspective of an external observer, relativistic time stands still within a black hole so that relativistically there is no motion within the black hole - and hence relativistically it must have a temperature of zero Kelvin.

But the other context of the frame of reference within the black hole must also be considered. Can we really be confident that the tremendously dense and tremendously hot object that first formed the black hole suddenly froze as a result of the black hole's formation?

We might need to consider that even though only a single oscillatory motion of a sub-atomic particle might occur within the remaining lifetime of the universe, there is still an unthinkably dense and unthinkably hot object inside that will play out its remaining lifespan across unthinkably long eons of time and persist well after all the remaining stars in the universe have aged and died out.

Question 2:

Dear Cheap Astronomy - just what the heck is gravitational potential energy?

Gravitational potential energy is more of a theoretical concept than something 'real'. The idea is simple enough though. If you fire a bullet straight up (and let's assume you do this in a vacuum), the bullet will follow a parabolic trajectory slowing as it reaches it maximum altitude - after which it will descend back downwards, accelerating as it falls. So, by the time that it is back near the ground, you will find that it is moving with exactly the same velocity that it had when it left the gun muzzle.

At the bullet's point of maximum altitude we say that it has a gravitational potential energy equivalent to all the actual energy that was used to propel it to this altitude. So all the energy involved in the rapid burning of gun powder to produce the compressed gas that then pushes the bullet out of the muzzle of the gun, is converted into the potential gravitational energy that is available when the bullet is at its maximum altitude.

Then, as it begins to fall back to Earth, that potential gravitational energy is converted back into actual momentum energy - being the mass of the bullet times the velocity it gets accelerated to. So energy is conserved and the first law of thermodynamics is upheld. Hooray for physics.

But, as we said earlier, it's not really energy in the conventional sense. Imagine that you are now standing on top of the Burj Khalifa and you fire your gun upwards. The bullet goes up, achieves a point of maximum altitude and then it begins to fall. As it passes you at 800 m above the ground it has the same momentum energy it had when it left the muzzle of your gun. But from there it keeps on falling an extra 800 metres towards the ground and it keeps on accelerating as it goes. So when it hits the ground it actually has more momentum energy than it did when it left the muzzle of your gun.

If that's not puzzling enough, try another experiment without the gun. If you just hold a bullet between your fingers and lift it up and then let it drop to the floor again, sure it gains momentum energy in the fall, but it's not an energy that was ever contained within the bullet itself. So, gravitational potential energy arises from the position of the bullet in space and time, not from the bullet itself.

In reality, or at least in Albert Einstein's reality, the bullet that you fire from a gun in a vacuum really does retain all the kinetic energy that was imparted to it when it was propelled from the gun muzzle. But when you watch it go up and see it nearly slow to a standstill at a high altitude, you are comparing your frame of reference to a totally different gravitational frame of reference where time is less dilated and distances are less scrunched up. So the bullet appears to slow to a standstill. It's only as the bullet follows its curved parabolic path and returns to your altitude that you are able to properly measure how it really does retain the same energy it had from the moment it left left your gun.

From the bullet's point of view it got shot out of a gun and then proceeded at a constant velocity until it hit the ground, all the way along carrying with it the same momentum energy that it had when it left the gun muzzle.

Gravity isn't really about energy - it's about curved space-time. So gravitational potential energy is just a kind of mathematical modelling - it's not 'real'.