An N type and I take a P type and I put them together, some really important things happen.

So important that it led to this, which is the very first transistor.

That's a transistor.

It's a dope semiconductor, one type, next to a dope semiconductor, another type.

Now, those are the three people-- Bardeen, Shockley, and Brattain-- who won the Nobel Prize for this work.

And that's the first transistor.

Does anybody know how many transistors we make today?

Per second.

That's the only time metric we can use.

Yeah, it's something around 10 trillion.

We make 10 trillion transistors per second today.

This is a big deal.

This started it all, and it's all about chemistry and the physics of this device.

This led to diodes and photodiodes.

This led to the whole revolution.

And what I want to point out here is that this also led-- it called on chemistry.

So I love this chart.

Unfortunately, they didn't update it, but this is an Intel chart that they used to show.

And what they're showing is how are they making chips.

How much of the periodic table do they need to make the current chip?

Well, in the '80s, there's almost nothing lit up here.

There's a little bit over here that you can't see, stuff we just talked about.

But look at the '90s and look at the 2000s.

And today, it's 75% of this.

It's literally 75% of this is in your phone.

Yeah.

Why?

The reason is exactly what we've talked about today, because they need more and more and more flexibility and ways to tune the band gap and the semiconducting properties of these materials and the doping.

Why do they need new ways?

Because they're making them so darn small.

They're so small, it gets harder to figure out how to do it right, how to do it in a way that's also stable over time, for example.

So they need new chemistry.

This is a call to action to the field of chemistry, and chemistry responded.

And there's the data on the cost.

I thought that was kind of cool.

So these are orders of magnitude of cost and number of transistors.

And I'll just say one more why this matters.

Because the semiconductor is also the same thing we use to take electricity from the sun, to generate electricity from the sun.

And you can imagine, you are doing that in your goody bag.

You're literally using this semiconductor to generate electricity by shining light on it.

Why is this important?

Well, I like this comparison.

All the coal, oil, and gas known to humans is what you get from the sun in about 20 days.

This is the sun.

Now, we've seen the sun before.

This is how we see it in our class.

The sun is a spectrum of different wavelengths and intensities.

And this is already on planet Earth, because you can see those chemistries that are in the atmosphere have already absorbed.

Remember ozone down here, helping us with UV radiation?

And out here, you've got a lot of water and other things, CO_2.

Those are absorbing.

That's why it doesn't look smooth.

But the point is, I want to semiconductor to absorb as much of this as possible.

If I want a good solar cell, I should absorb as much of this as possible.

But the problem is that it's a constrained optimization problem.

So let's see, if I-- I'll just use this.

This goes back to Bohr, by the way.

Remember, Bohr, I'm absorbing light.

It's just now, I've got an actual solid.

I don't have an atom.

I've got a solid, which is what you need if you want to generate a current.

I've got to hook leads up to it.

But my solid is a semiconductor.

And you can imagine, say, well, if my gap were really, really tiny, then any amount-- almost any amount of this spectrum would excite electrons.

And I might grab most of that spectrum.

I might absorb most of it.

But the problem with that is that, then, all of these will thermalize, like I said in the beginning.

Loss to heat.

Loss to heat.

So if my band gap is really small, I absorb a lot of the light, but I lose most of it as heat.

If my band gap is really big, then there's so much of this light that I cannot absorb.

By the way, also, the voltage that you get out of your solar cell is essentially this band gap.

So if I get to really, really small band gaps, I have almost no voltage.

That's bad, too.

But if my band gap is too big, you think, oh, I'll get a high voltage.

No.

You won't absorb any photons.

So it's a constraint problem.

It's a constraint problem.

You can actually solve this, and you can plot-- in fact, here's a little animation.

Energy comes in from the sun.

It excites an electron.

This is how PowerPoint sees it.

Leaves behind a hole, and you get them out.

That's a solar cell.

And this is the chart I want to show you.

Because you see, if I take this constraint into account, that I don't absorb light if the gap is too big, but I do absorb light and it all goes to heat if the gap is too small, it means there's some sweet spot.

There's some sweet spot.

And that's what is plotted here.

This is the band gap of a semiconductor, and this is the maximum that that solar cell efficiency could be.

That's the maximum that it could be for that gap.

So you can see the sweet spot is right there.

That's a thermodynamic derivation called Shockley-Queisser of the maximum efficiency you could ever get out of a single material.

And notice, if you put the materials here, silicon is 90% of the solar cells you buy today.

And notice that it's not quite at its maximum potential.

It's also not quite in the middle, where you'd want.

It should have a slightly higher gap, and you'd get to higher efficiency.

But these materials out of gallium arsenide, they do have the-- what is GS?

That's not an element.

Gallium arsenide, it does have a better gap, but it's much more expensive.

And so we go.

And a lot of solar cell research is on getting as close to this point as you can.