

**PROFESSOR:** Mendel's second law-- this thing over here about a three to one ratio about a single trait being controlled by a pair of alleles, and those alleles being distributed independently of each other to the offspring, the stuff you always learned about Mendel-- that's often referred to as Mendel's first law. Mendel, by the way, didn't call it Mendel's first law. It's considered-- you don't write that in your own papers or something like that, right?

So Mendel did actually observed some other things beyond this independent segregation of the alleles for a single trait. Mendel began to cross his peas together and try to make combinations. He had rounds and wrinkles. He had greens and yellows, talls and shorts. He started making combinations.

How about a plant that was wrinkled and yellow? Green was the normal color. Round was the normal shape. But he had yellows. He had wrinkleds. How about making a combination? So he begin to make plants that bred true for different pairs of phenotypes.

So for example, he had a pure breeding line here that was both round and green. That was the stuff he could pick up at the market. But he made a line here that was both wrinkled and yellow. What is the genotype of this round, green strain? At the round gene-- the gene for roundness- what is its genotype?

Big R, big R. It's a pure breeding strain. It was homozygous-- we're just testing our words here-- homozygous for the big R allele. Green is controlled by a different gene. It has an allele big G. It's pure breeding for this. And we call it big G, big G.

Convention, when we use capital letters, it tends to mean that the associated phenotype is dominant. OK? It'll make you think that the allele is dominant, but it's the associated phenotype that's dominant.

Now, wrinkled-- what was wrinkled? Wrinkled was a homozygous wrinkled-- little r, little r. And what was the genotype at the yellow locus? Little g, a little g is how we'll denote it. Geneticists use four or five different kinds of notations. We're going to use

this notation today of big R's and little r's and little g's. But you'll get used to other kinds of genetic notations.

So when we cross these guys together, this F0 generation here of these two pure breeding parental strains, we get an F1 generation. The F1 generation-- what is it phenotypically? What did it look like?

Round and green, yep-- round and green. What was in genotypically? Big R, little R, big G, little g. Now we could self these plants. And our head would hurt with the nine to three to three to one ratio. So instead, why don't we cross these plants back to the wrinkled, yellow strain to make our life easier?

Little r, little r, little g, little g-- and when we cross that back, what is the segregation that's going to happen? Well, what are the possible gametes that could emerge from this parent? We could get a big R and a big G. We could get a big R and a little g. We could get a little r and a big G. We could get a little r and a little g. Those are the four possibilities that could be contributed by this parent.

What could be contributed by this parent? Little r and little g-- that's it, right? No other options. So that's what our little Punnett square looks like here of our options-- parent number one, parent number two.

What will this be? This will be big R, big G over little r, little g, big R, little g over little r little g, little r, big G over little r little g, little r little g over little r little g. In other words, this will be round and green. This'll be round and yellow. This'll be wrinkled and green. And this'll be wrinkled and yellow.

And what will be the ratio of these? One to one to one to one, provided that those gametes were all equally frequent, provided that that parental plant made each of those four types in equal proportions. That one to one to one ratio in the gametes will necessarily translate into a one to one to one ratio in the phenotypes observed in the next generation.

When we cross back-- not by selfing-- but when we cross back to the parent that has the recessive phenotypes, we'll often call this a backcross or a test cross. If I

haven't done a backcross or a test cross where I crossed back to the wrinkled, yellow parent, I would instead have had to make a square here that had 16 boxes in it, and I would have had to add up to 16 boxes to figure out how many were round and green-- nine out of the 16. How many were round and yellow? Three out of the 16. How many were wrinkled and green? Three out of the 16. And how many were wrinkled and yellow? One out of the 16.

But for the purposes of using the white board up here, I did the test cross or the backcross, because it's simpler. But you can also do the four by four matrix and figure out what it looks like.

That was news. It didn't have to be that way, right? Maybe it was something else. This is pretty cool. What it tells you is not just is it the case that here the alleles segregate independently.

It's a random coin flip which one you get. It tells you no correlation between the two traits. They're independent. This is called independent assortment. Mendel's second law is the law of independent assortment. All right.

So Mendel publishes the paper. 1865, it comes out. Here's a copy of Mendel's paper. It's translated into English from the original German. So I got Mendel's paper here. There's no Punnett squares. It's kind of messy notation. Look at that. Look at all that-- big A, little b. He's got A's, B's, C's. He's got three factor crosses running around in here.

Mendel really goes to town. It's a beautiful paper here. But it just goes on and on. It's incredibly hard to read. Look at this. It takes a lot to read this thing. But in a way, it's simple. It's nothing so sophisticated. Oh yeah, here. Look at this-- long, green, inflated, constricted-- all this kind of stuff. It's pretty cool. You should look it up. It's online. You can find Mendel's paper.

What happens to Mendel's paper? Nobody reads it. It sinks like a stone. It's this cool paper and nobody reads it. Nobody reads it for a lot of reasons. Scientific communication wasn't so big in those days. Oh, well.

Mendel also ends up getting promoted to become the abbot of the monastery, and that's pretty much the end of his scientific career, in my opinion. He got too many administrative duties, doesn't do more science there.

Also, he has some poor choices. The next plant he works on is hawk weed. Hawk weed turns out to have really weird genetics that totally leads him astray. Basically, this is the one important paper Mendel ever publishes.

It's an incredibly important paper. It's so important because it contains the clue to what Darwin, living at exactly the same time, wished he understood, which is what the basis of genetic variation is. Wouldn't it be great if Darwin had read Mendel's paper?

Darwin actually owned a copy of Mendel's paper. He received a copy of Mendel's paper. In those days, the way they printed books, there were folded pages and you had to slit the page to read it. Darwin never slit the pages of the copy of Mendel's paper. So we know he's never read Mendel's paper, but he has one in his library. He had Mendel's paper. He had the answers sitting there on the shelf, but never read it.

The stuff sinks like a stone. Nobody really pays much attention to it. And Mendel goes on, dies that's it.

[LAUGHTER]

**PROFESSOR:** Until the end of the 1800s, right at the beginning of the 20th century, along comes cytology-- looking at cells in the microscope. Microscopes began to get good in the late 1800s. And cytologists began to see in their microscope that when cells divided, these funny structures began to appear-- these long, thread-like things.

And the German chemical industry being developed at that time had invented all sorts of dyes. And cytologists began experimenting putting dyes on these cells. And the dyes let them see really clearly these funny things that were condensing out when cells divided.

And they had no clue what these funny things were other than that they took up dyes. And so in the absence of any clue what were, they called them chromosomes, meaning colored things. That is what chromosome means. They called them colored thing Chromos colored bodies, colored things. That's all they knew.

And they observed that these chromosomes, these colored things, did really interesting choreography. When cells divided, when they underwent mitosis, what would happen is that the chromosomes would line up along the midline. And they would have, at that point, these funny X-like structures.

And I'll draw four of these chromosomes lining up like this. And what would happen during mitosis? The cell would divide, and each of the two cells would get one half of the X. So if you started with four of these X's, you ended up with four like this. There you go.

That was the chromosome being somehow tugged apart. Now, anything that gets tugged apart when a cell divides-- that's kind of interesting. Then those chromosomes would disappear. You couldn't see them again for a while until the cell was ready to divide again.

And when the cell is ready to divide again, darned if those single lines hadn't turned into X's. Somehow the cell had turned the single lines into these two pieces, these X's, and they were ready to divide again. And that was mitosis-- the process of ordinary cellular division.

But there was another process. Folks observed meiosis. That's what happens when you make gametes. So when gametes get made, the choreography was a bit different. Instead of all the chromosomes lining up on the midline as individuals, they lined up as pairs. They line up as pairs.

When the cell divides, you end up with now only two X's, not four X's. Then what happens is those cells divide again. And you end up with those straight lines-- but not four of them, only two of them.

The first step gets called meiosis number one-- meiosis I. The second is called

meiosis II. The second step looks just like mitosis, doesn't it? Chromosomes are lined up along the midline. They separate it. It just looks like mitosis, ordinary cell division.

But that first step is special. That first step says, somehow, the chromosomes come in pairs, and the cell picks one from each pair and gives to its gametes-- its sperm or its egg-- one from each pair. And what do you think happens on fertilization?

Well, you had one from each pair, one from each pair, it comes together and it restores a pair now. And you know what folks said? They said this sounds just like what that dead monk was talking about. Pairs, particles of inheritance-- particles that come in pairs and you give to your gametes one of the two pairs. These colored things must be the basis of inheritance or genes or something.

Wow, because it fits Mendel's model beautifully. It explains the first law. What about the second law? What about Mendel's second law? How could it explain the big R and the big G being inherited independently of each other with no correlation? What would that have to mean?

They're on different chromosomes. The genes are on different chromosomes. Because if big R is on one chromosome and big G is on the other chromosome, then it's a coin flip whether or not the big R might be here and a little r might be there or the big G might be there or maybe it's over there. It's a random draw which way it's going to go.

So it perfectly explains Mendel's second law. Unless-- what happens if big R and big G are on the same chromosome? Then they're going to go together. I'm not going to have independent assortment. I may have totally dependent correlated assortment. If big R and big G are on the same chromosome, they're going to be inherited together. Mendel's second law is going to be wrong.

So why did Mendel find big R and big G going together? Maybe was lucky and he picked traits on different chromosomes. But what about his next trait? Lucky again? Lucky again? Mendel studied seven traits. How many chromosome pairs do peas

have?

Turns out, seven. But anyway, what happens? What's going on? Mendel's second law can't be right if the chromosome theory is right when the genes are on the same chromosome. They would be dependent. They won't be independent one to one to one to one.

So which is it? Is Mendel right, my hero? Or is this chromosome theory right? Because they can't be both perfectly right. So which is it? Oops, we've run out of time.

[LAUGHTER]

**PROFESSOR:** Next time.