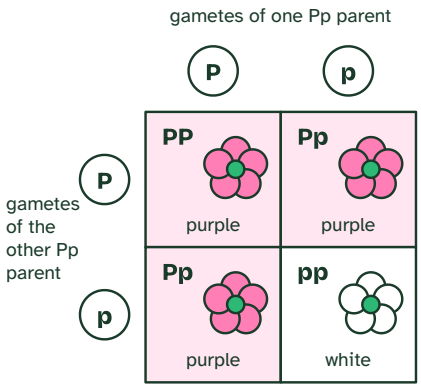
Predicting the *offspring*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Each parent passes on one of its two alleles of a gene, at random. So offspring come in ratios you can predict, and test.



Draw it like this. One parent's gametes along the top, the other's down the side. Each box is one equally likely offspring.

5.3.A THE LAW OF SEGREGATION

Two alleles in, *one allele out*

- A diploid organism has two alleles of each gene, one on each chromosome of a homologous pair.
- **Law of segregation**: the two alleles of a gene separate into different gametes, so each gamete carries one. The cause is meiosis: **homologous chromosomes separate in meiosis I**.
- Fertilization fuses two haploid gametes. It restores the diploid number and gives the zygote a new combination of alleles.
- Pp × Pp gives a **genotypic ratio** of 1 PP : 2 Pp : 1 pp and a **phenotypic ratio** of 3 purple : 1 white.

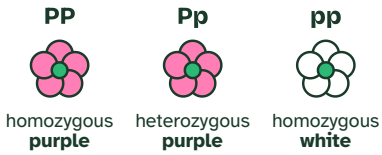
THE GENERATIONS OF A CROSS — *Parents First, Second Follows*

P Parents	**F** First	**S** Second
P: the true-breeding plants crossed	F1: their offspring	F2: offspring of two F1 plants

5.3.A GENES, ALLELES, TRAITS

The *words*

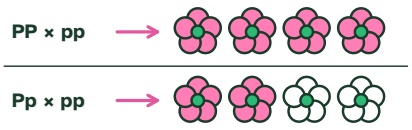
- A **gene** is a length of DNA at one **locus** on a chromosome. Its versions are **alleles**.
- **Genotype**: the alleles inherited. Two the same is **homozygous**; two different is **heterozygous**.
- **Phenotype**: the observable expression of the traits.
- By convention a capital letter is the dominant allele and a small letter the recessive one.
- A **dominant** allele shows in a heterozygote. A **recessive** allele shows only in a homozygote.



5.3.A A HIDDEN GENOTYPE

The *test cross*

- A purple plant could be PP or Pp. You cannot tell by looking.
- **Test cross**: cross it with a **homozygous recessive**, pp. That parent adds only p, so the offspring show the unknown parent's gametes.
- Any recessive offspring means the unknown parent was heterozygous.
- Which allele is dominant? Cross two true-breeding parents that differ: it is the trait every F1 shows.
- A square works backward too: from the offspring you can deduce the parents.



5.3.A RULES OF PROBABILITY

"And" multiplies, *"or" adds*

- **Multiplication rule:** for **independent** events, P(A and B) = P(A) × P(B). Aa × Aa gives aa with chance 1/2 × 1/2 = 1/4.
- **Addition rule:** for **mutually exclusive** events, P(A or B) = P(A) + P(B). Aa can form two ways: 1/4 + 1/4 = 1/2.
- **Several genes** on different chromosomes: one gene at a time, then multiply.

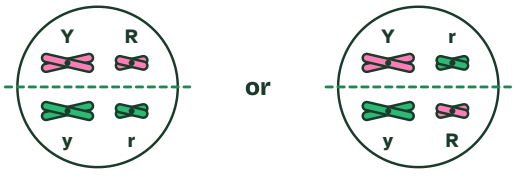
Worked AaBbDd × AaBbdd
Shows A, is bb and is Dd: 3/4 × 1/4 × 1/2 = **3/32**.

No memory
Each fertilization is independent: the chance is the same for every offspring.

5.3.A THE DIHYBRID CROSS

Two genes: *independent assortment*

- **Law of independent assortment**: the alleles of one gene pass into gametes independently of the alleles of another. It holds for genes on **different chromosomes**.
- The cause is meiosis: each homologous pair lines up on its own at **metaphase I**. So a YyRr plant makes four kinds of gamete in equal numbers.
- YyRr × YyRr gives **9 : 3 : 3 : 1**, which is two 3 : 1 ratios multiplied: 3/4 × 3/4 = 9/16 show both dominant traits. The test cross YyRr × yyrr gives **1 : 1 : 1 : 1**.



gametes YR and yr or **gametes Yr and yR**

Testing a ratio, reading a *pedigree*, giving the chance

5.3.A TESTING A RATIO

Chi-square: close enough, or too far to be chance?

FIVE STEPS

Hungry Elves Cook Delicious Cakes

H Hypothesis: the null: the counts fit the ratio	**E** Expected: total × each fraction of the ratio	**C** Calculate: sum of $(o - e)^2 \div e$	**D** Degrees: of freedom: outcomes minus one	**C** Compare: with the critical value at $p = 0.05$

- **Null hypothesis**: there is no significant difference between the observed counts and the counts the ratio predicts.
- Chi-square **above** the critical value: **reject** the null hypothesis. At or below it: **fail to reject**.
- It is for **counts in categories**, not means, measurements or percentages. The formula and the critical values are on the AP equations sheet.

MENDEL'S F2 SEEDS	OBSERVED	EXPECTED	$(O - E)^2 \div E$
Round, yellow	315	312.75	0.02
Round, green	108	104.25	0.13
Wrinkled, yellow	101	104.25	0.10
Wrinkled, green	32	34.75	0.22

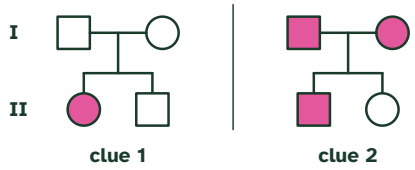
Expected from 9 : 3 : 3 : 1 of 556 seeds — Chi-square = **0.47**

Four outcomes, so 3 degrees of freedom: the critical value is 7.81. 0.47 is below it: fail to reject. Critical values at $p = 0.05$: 3.84 (1), 5.99 (2), 7.81 (3).

5.3.A READING A FAMILY

A *pedigree* is data

- Squares are males, circles are females and a filled symbol shows the trait. Generations are numbered I, II, III.
- **Clue 1:** unaffected parents with an affected child. The allele is **recessive**, and both parents are heterozygous **carriers**.
- **Clue 2:** affected parents with an unaffected child. The allele is **dominant**, and both parents are heterozygous.
- Then deduce genotypes from the people you are sure of: anyone who shows a recessive trait is aa. Where two genotypes fit, write A_.



5.3.A PATTERN, THEN CHANCE

From data to a *prediction*

- Ask two things. Dominant or recessive? And **autosomal** (not on a sex chromosome) or not? An autosomal trait affects males and females alike.
- A trait that vanishes in the F1 and returns in a quarter of the F2 is recessive.
- Sexes not affected alike: suspect a **sex-linked** gene. Two traits staying together more than 9 : 3 : 3 : 1 allows: suspect **linked** genes.
- With the pattern known, the rules of probability give the chance for the next offspring.

1/4 chance that each child of two carriers shows the recessive trait

2/3 chance that their unaffected child is a carrier: aa is ruled out

WATCH OUT

Five mistakes that *cost points*

- ✕ **Dominant does not mean common, strong or better.** It only describes what shows in a heterozygote.
- ✕ **1 : 2 : 1 counts genotypes; 3 : 1 counts phenotypes.** Give the one the question asks for.
- ✕ **A gamete carries one allele of each gene.** YyRr makes YR, Yr, yR and yr: never Yy or Rr.
- ✕ **A ratio is a chance, not a promise.** Four offspring need not be 3 and 1, and earlier ones change nothing.
- ✕ **"Fail to reject" is not "proved".** Never write "accept" the null hypothesis.

COVER THE SHEET

Can you *answer these?*

1. Explain the law of segregation using meiosis.
2. Explain why a test cross uses a recessive parent.
3. Calculate the chance of aabb from AaBb × AaBb.
4. Explain why a YyRr plant makes four kinds of gamete.
5. Calculate chi-square for 290 and 110 against 3 : 1.
6. Justify the degrees of freedom for a 3 : 1 test.
7. Identify the pattern: affected parents, unaffected child.
8. Predict the chance two carriers' next child is affected.

IN THE EXAM

State the null hypothesis in terms of the cross: "no significant difference between the observed counts and those expected from 3 : 1". Show the expected counts, then end on "reject" or "fail to reject".

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.