What about two traits?
Dihybrid Crosses

- **Consider two traits for pea:**
  - **Color:** Y (yellow) and y (green)
  - **Shape:** R (round) and r (wrinkled)

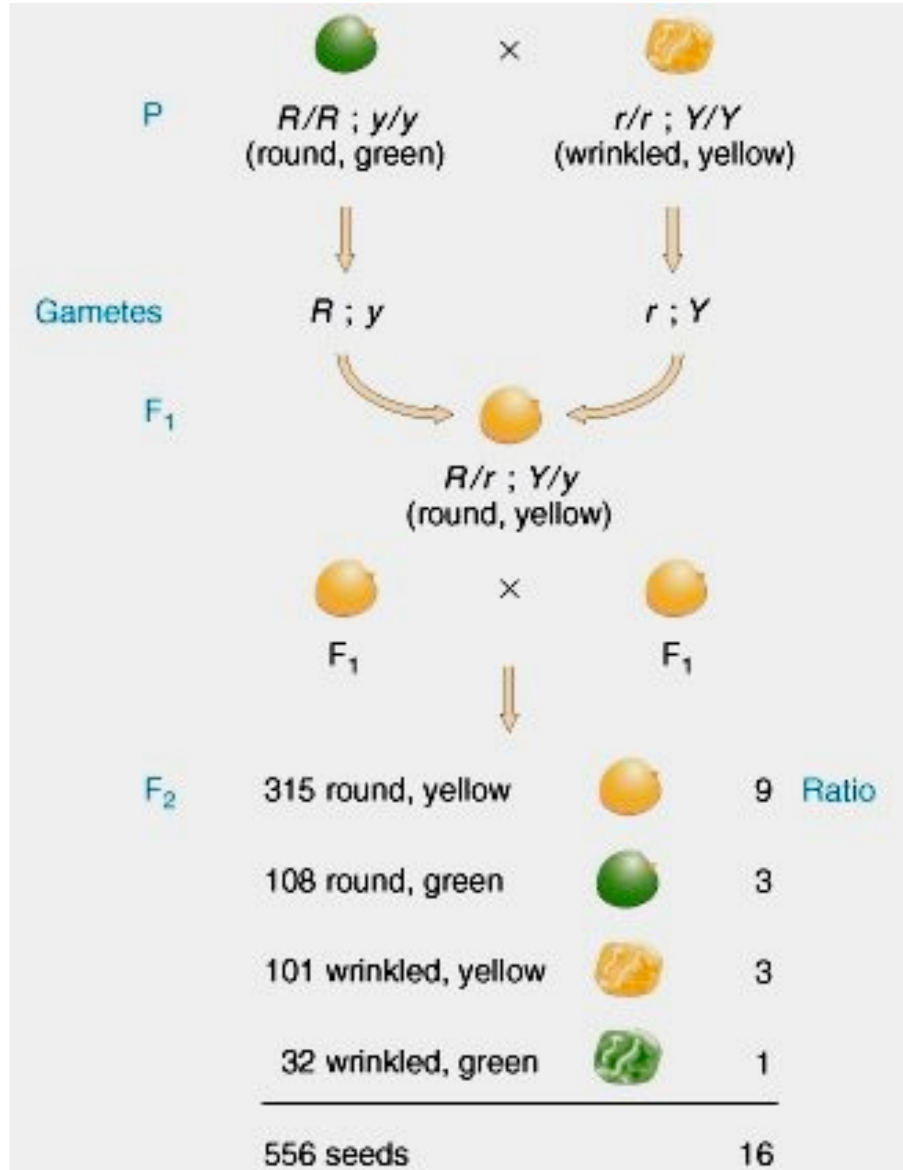
- Each **dihybrid** plant produces 4 gamete types of equal frequency.
  - **YyRr** (adult)→ four gamete types: **YR**, **Yr**, **yR** or **yr**

Dihybrid crosses reveal the law of independent assortment

- A dihybrid is an individual that is heterozygous at two genes (YyRr)
- Mendel designed experiments to determine if two genes segregate independently of one another in dihybrids
  - First constructed true breeding lines for both traits (YYRR & yyrr)
  - crossed them to produce dihybrid offspring (YyRr)
  - examined the F2 for parental or recombinant types (new combinations not present in the parents)

Tracking Two Genes

- Pure-breeding parentals
- F1 are all RrYy
- Self or cross F1
- Observe 9:3:3:1 ratio
- Note that the round green and wrinkled yellow phenotypic combinations observed in the parents did not stay together in the offspring.



Results of Mendel's dihybrid crosses

- F2 generation contained both parental types and recombinant types
- F2 showed 4 different phenotypes: *the round and yellow traits did not stay linked to each other*.
- Ratios for each trait corresponds to what one would expect from monohybrid crosses.
- Alleles of genes assort independently, and can thus appear in any combination in the offspring
- *Shuffling of traits occurs before they realign in every possible combination.*

What ratios were produced per trait?

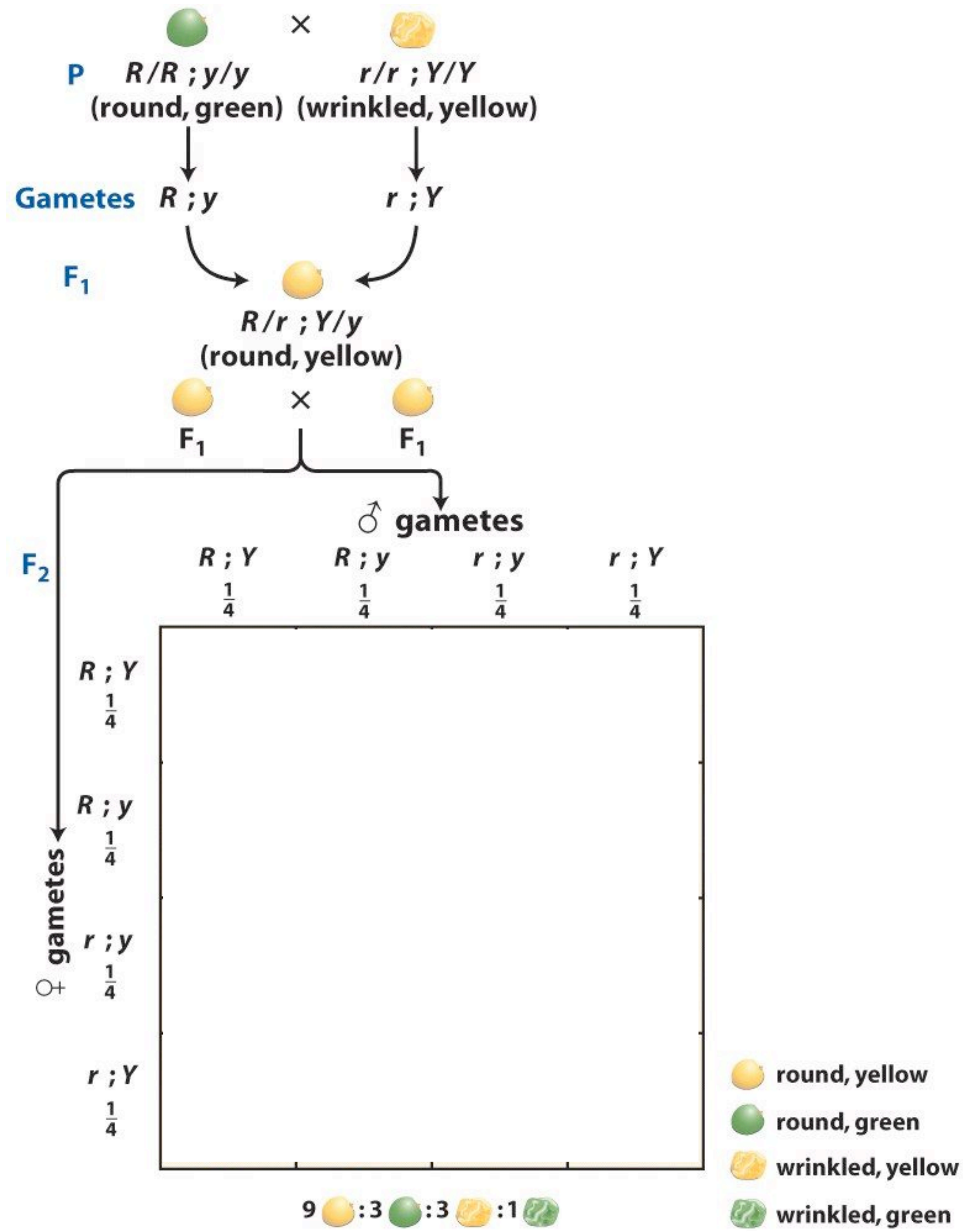
315	round yellow	9	R-Y-
108	round green	3	R-yy
101	wrinkled yellow	3	rrY-
32	wrinkled green	1	rryy

Shape	Color
round : wrinkled	yellow : green
315+108 : 101+32	315+101 : 108+32
423 : 133	416 : 140
3.2 : 1	3 : 1

How can the F2 proportions be explained?

A Punnett square of dihybrid cross

- Each F1 produces four different types of gametes in equal proportions
- These gametes come together randomly to form a zygote
- Each single trait still gives 3:1 ratio
- Combined, the overall ratio is 9:3:3:1



A Punnett square of dihybrid cross

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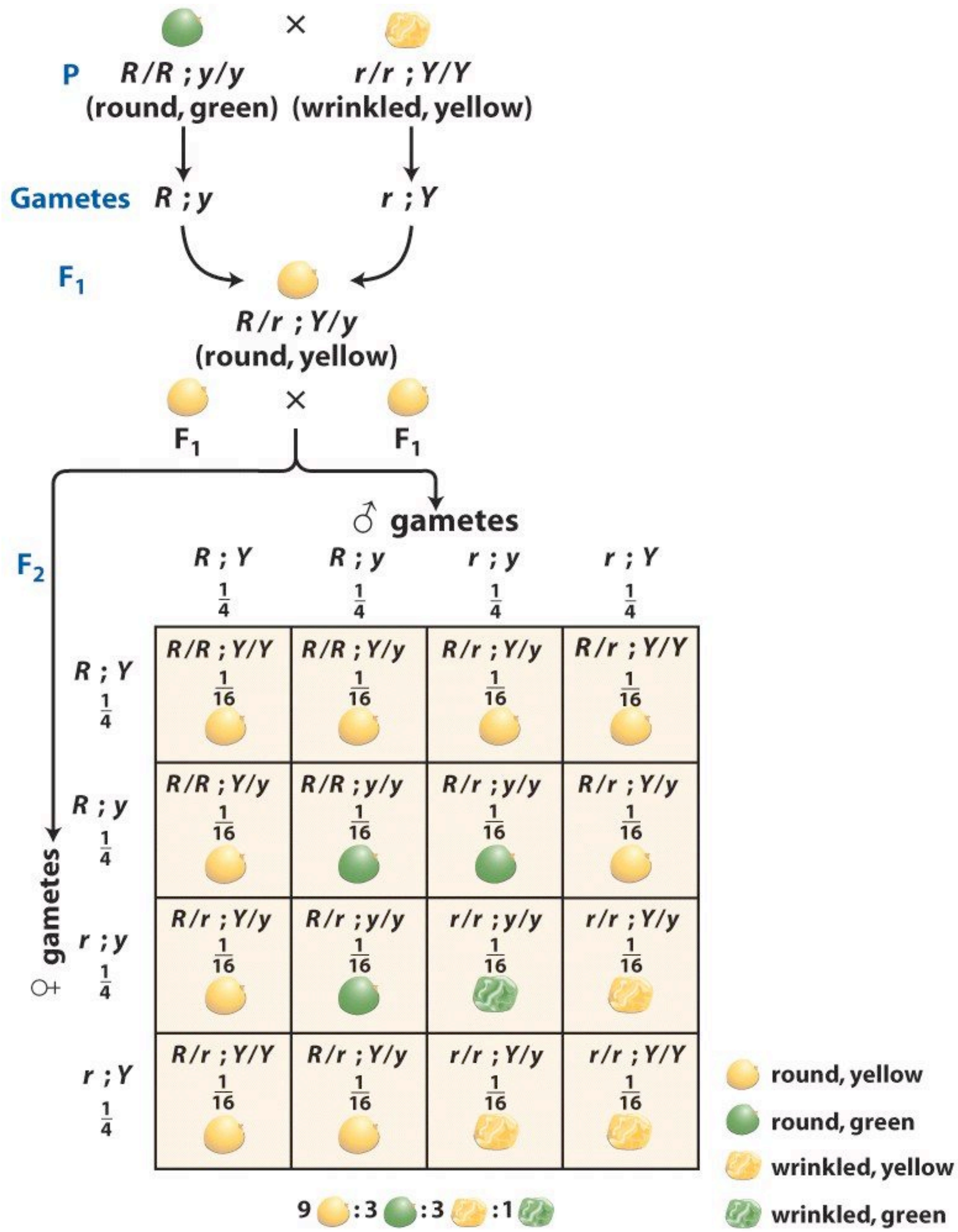


Dihybrid cross produces a predictable ratio of phenotypes

Type	Genotype		Phenotype	Number	Phenotypic ratio
Parental	*Y– R–*		yellow round	315	9/16
Recombinant	*yy R–*		green round	108	3/16
Recombinant	*Y– rr*		yellow wrinkled	101	3/16
Parental	*yy rr*		green wrinkled	32	1/16

Ratio of yellow (dominant) to green (recessive) = 12:4 or 3:1

Ratio of round (dominant) to wrinkled (recessive) = 12:4 or 3:1

Hints for Dihybrid Crosses

- Look at all combinations of gametes
  - Remember only one allele per gene is represented

- Not all squares are 4 by 4's
  - TTPp X Ttpp What would square sides look like?
    - TP and Tp on one side
    - Tp and tp on the other

- Need to clearly state phenotype and genotype ratios for full credit on exams!

Dihybrid Crosses

TTPp X Ttpp

	Tp	TP
Tp		
tp		

Dihybrid Crosses

TTPp X Ttpp

	Tp	TP
Tp	TTpp	TTPp
tp	Ttpp	TtPp

Dihybrid Crosses

TTPp X Ttpp

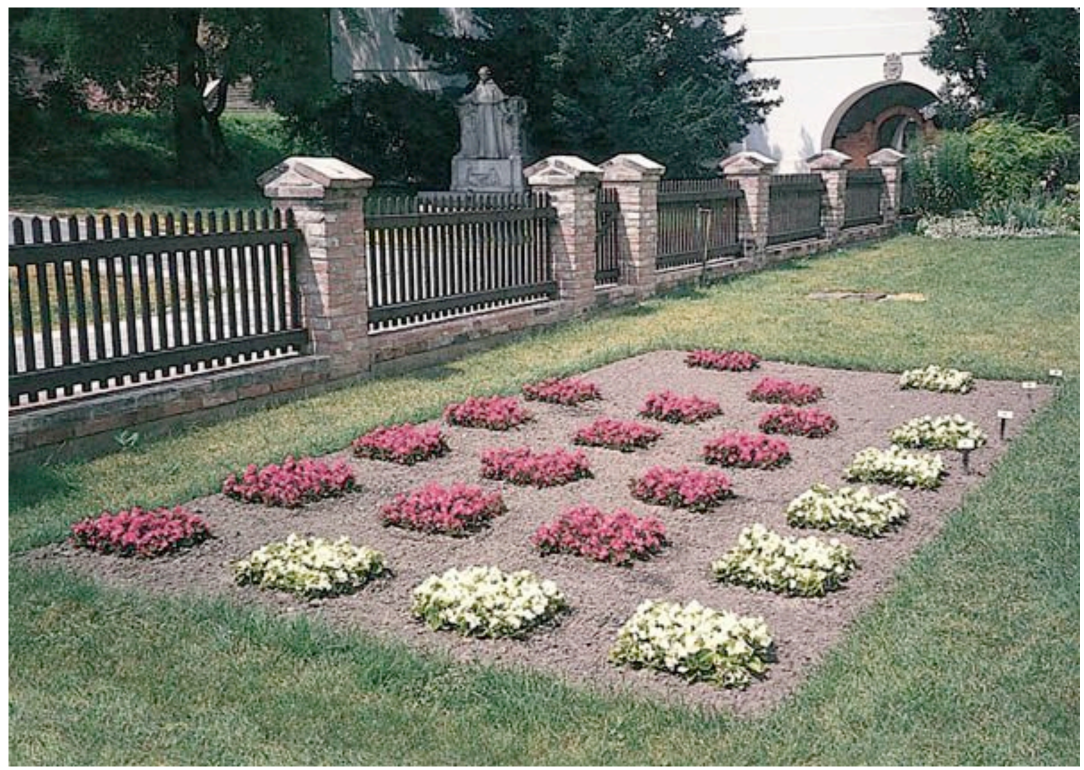
	Tp	TP
Tp	TTpp	TTPp
tp	Ttpp	TtPp

Genotype ratio: 1TTpp: 1TTPp : 1 Ttpp : 1 TtPp

Phenotype ratio: 1 tall, purple: 1 tall, white

Mendel's Second Law

- **Law of independent assortment**:
  - Segregation of alleles of two different genes are independent of one another in the production of gametes
  - For example:
    - no bias toward YR or Yr in gametes
  - Random fertilization of ovules by pollen
    - no bias of gametes for fertilization



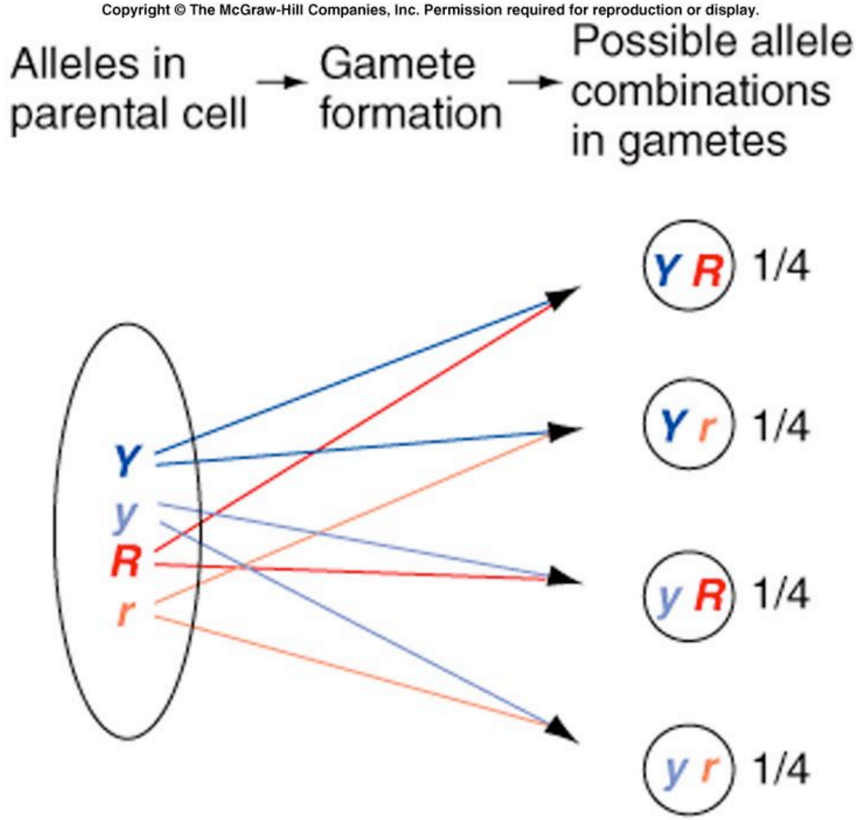
Mendel's Monastery in Brno

Law of Segregation:

- Two alleles for each trait separate (segregate) during gamete formation, and then unite at random, one from each parent, at fertilization

The law of independent assortment

- During gamete formation different pairs of alleles segregate independently of each other



Dihybrid Testcross

The dihybrid should make four types of gametes, in equal numbers

YR Yr yR yr

F1 YyRr round yellow X yyrr wrinkled green

YyRr	- yellow round	31
Yyrr	- yellow wrinkled	27
yyRr	- green round	26
yyrr	- green wrinkled	26

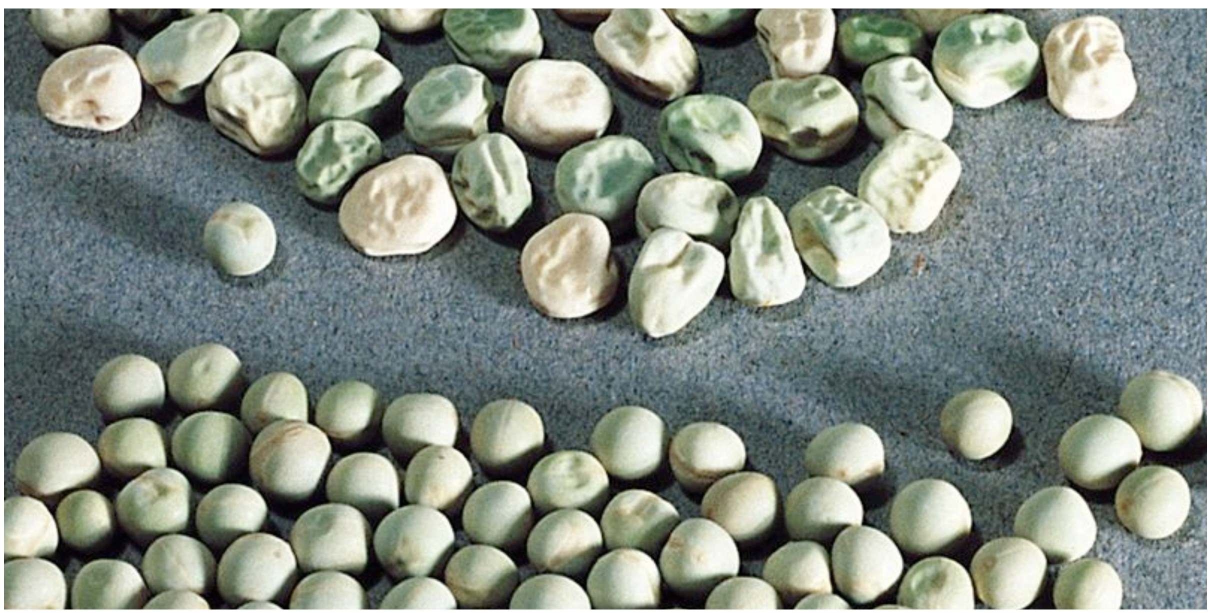
This is a ratio of 1:1:1:1

Test cross confirms ***independent assortment*** *of characters.*

Patterns of Segregation

- One gene (one trait, two phenotypes)
  - 3:1 (F2) phenotypic ratio
  - 1:2:1 (F2) genotypic ratio
  - 1:1 (or 1:0) phenotypic ratio in test cross of F1

- Two genes (two traits, four total phenotypes)
  - 9:3:3:1 (F2) phenotypic ratio
  - 1:1:1:1 phenotypic ratio in test cross of F1



Mendel's Laws

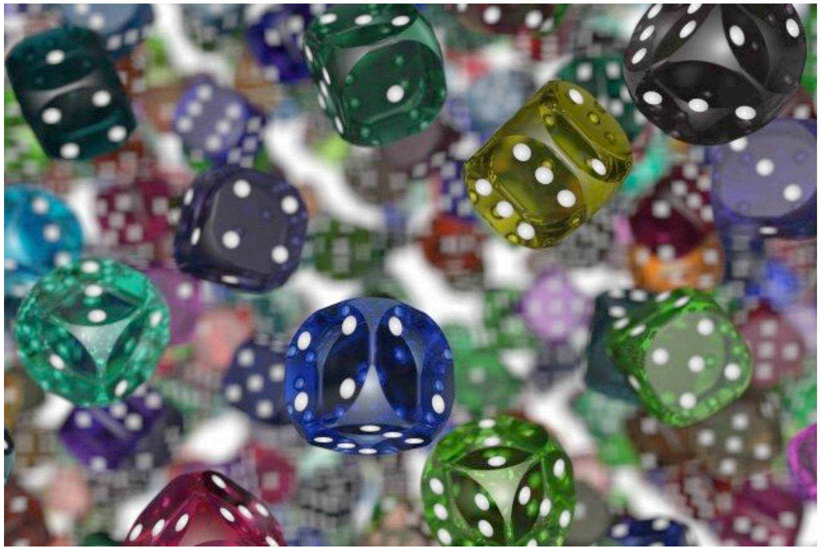
Law of Dominance: In a cross of parents that are pure for different traits, only one form of the trait will appear in the next generation. Offspring that have a hybrid genotype will only exhibit the dominant trait.

Law of Segregation: During the formation of gametes (eggs or sperm), the two alleles responsible for a trait separate from each other during a process called meiosis. Alleles for a trait are then "recombined" at fertilization, producing the genotype for the traits of the offspring.

Law of Independent Assortment: Alleles for *different* traits are distributed to eggs or sperm (& offspring) independently of one another. (These assortments can be determined by performing a dihybrid cross)

Probabilities and more Mendelian Analysis

- Review of probability
- Application of probability to Mendelian genetics

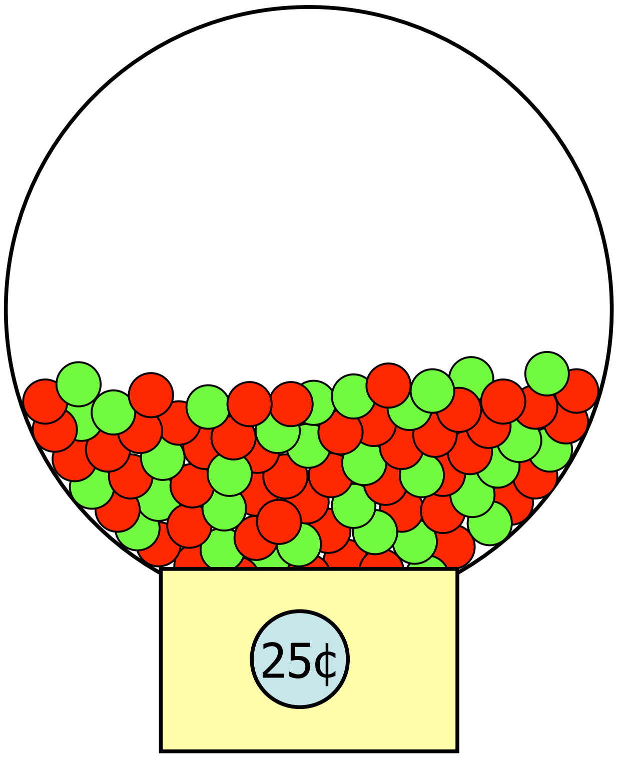


Probability
(expected frequency)

$$\text{probability of an outcome} = \frac{\text{\# of times event is expected to happen}}{\text{\# of opportunities (trials)}}$$

- The sum of all the probabilities of all possible events = 1 (100%)

Probability



- 60 red gum balls
- 40 green gum balls

> If you buy one gum ball, the probability of getting a red one is:

$$\frac{\text{\# of red gum balls}}{\text{Total \# of gum balls}} = \frac{60}{100} = 0.6$$

0.6 x 100% = 60%

Product Rule

The probability of *independent* events occuring together is the product of the probabilities of the individual events.

p(A and B) = p(A)p(B)

- If I roll two dice, what is the chance of getting two 5's? → a 5 on 1^{st} die **and** a 5 on 2^{nd} die?

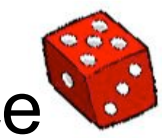
and

Product Rule

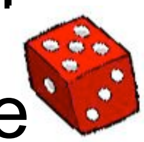
Note: the probability of getting a 5 on the second die is **independent** of what the first die shows.

Two events:

--probability of a 5 on the 1st die → $\frac{\text{a 5 on a face}}{\text{6 faces total}} = \frac{1}{6}$



--probability of a 5 on the 2nd die → $\frac{\text{a 5 on a face}}{\text{6 faces total}} = \frac{1}{6}$



✓ Prob. of a 5 on the 1st die and a 5 on the 2nd die =

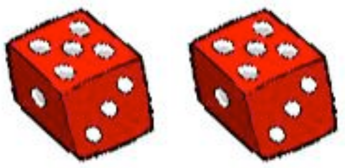
$$\frac{1}{6} \times \frac{1}{6} = \frac{1}{36} \qquad \sim 2.8\%$$

Sum Rule

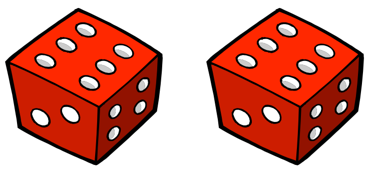
The probability of *either* of two mutually exclusive events occurring is the sum of their individual probabilities.

$$p(A \text{ or } B) = p(A) + p(B)$$

- If roll two dice, what is the chance of getting two 5's or two 6's? → a 5 on 1st die **and** a 5 on 2nd die **or** a 6 on 1st die and a 6 on 2nd die?

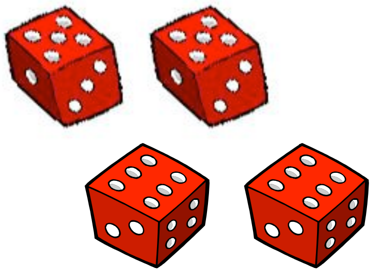


or



Sum Rule

--probability of getting two 5's = 1/36
--probability of getting two 6's = 1/36



✓ The prob. of getting either two 5's or two 6's =

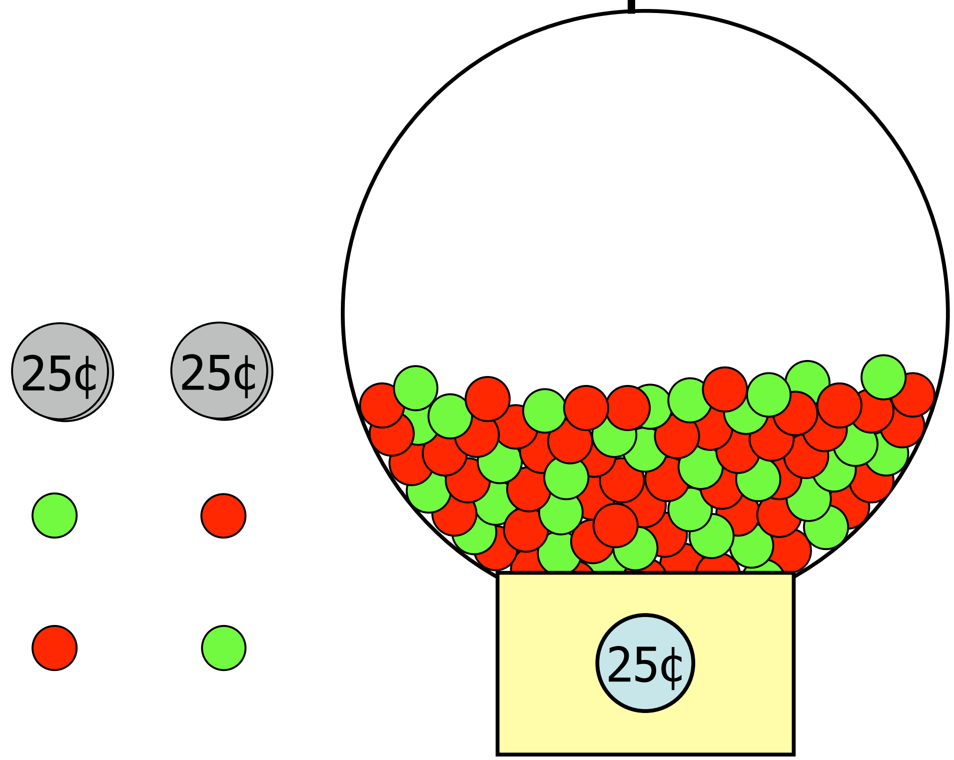
$$\frac{1}{36} + \frac{1}{36} = \frac{1}{18} \qquad \sim 5.6\%$$

Probability

What is the probability of getting one green and one red gum ball if we have two quarters?

- This can happen in two ways: green first then red, **or** red first then green.

- When not specifying order, we must figure out each way of getting the outcome.



60 red gum balls
40 green gum balls

Probability

p(green, then red) = p(green) X p(red) → product rule

= 0.4 X 0.6 = 0.24

-- or --

p(red, then green) = p(red) X p(green) → product rule

= 0.6 X 0.4 = 0.24

✓ Thus, the probability of getting one red and one green gum ball is

p(green, then red) + p(red, then green) =

0.24 + 0.24 = 0.48

→ sum rule

Probability

The Punnett Square is a way of depicting the product rule. Using Mendel's law of segregation, we know that both alleles are equally likely to occur. So for a cross:

Rr x Rr

F1 male gametes

F1 female gametes		1/2 R	1/2 r
	1/2 R	RR 1/4	Rr 1/4
	1/2 r	Rr 1/4	rr 1/4

monohybrid cross (one gene)

1/4 RR + 1/2 Rr + 1/4 rr

1 : 2 : 1

Question

- What are chances of two heads in a row with a fair coin?
- 1) 100%
- 2) 50%
- 3) 25%
- 4) 0%

Question

- What are chances of rolling a one or a two with a die?
- 1) 1/6
- 2) 2/6
- 3) 1/12
- 4) 1/2

Question

- If the parents of a family already have two boys, what is the probability that the next two offspring will be girls?
  - 1. 1
  - 2. 1/2
  - 3. 1/3
  - 4. 1/4

  - Hint: probability of 2 events occurring together

Dihybrid Cross: Two Genes

- Consider the two genes (each with two alleles):
  --color: Y (yellow) and y (green)
  --shape: R (round) and r (wrinkled)

cross two pure-breeding lines:

x

P

RRyy   rrYY

↓

F1

RrYy
(dihybrid)

Dihybrid Cross:

F1 (self)

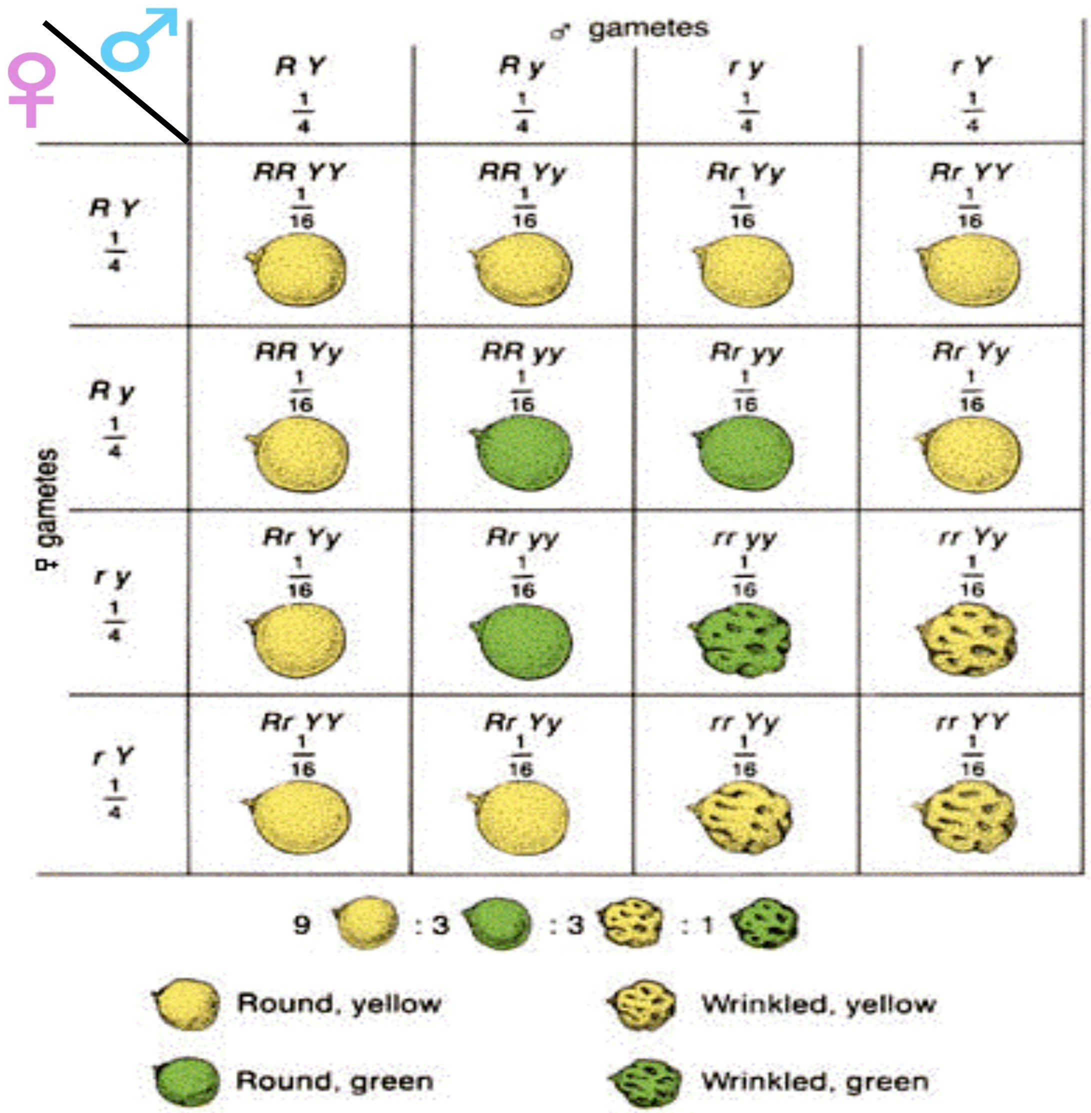
 X 

RrYy RrYy

all possible gametes: RY Ry rY ry
(from each plant)

$$p(\text{RY gamete}) = \frac{1 \text{ RY gamete}}{4 \text{ gametes}} = \frac{1}{4}$$

Punnett Square of a dihybrid cross



9/16 = round, yellow (R_Y_)

3/16 = round, green (R_yy)

3/16 = wrinkled, yellow (rrY_)

1/16 = wrinkled, green (rryy)

- Using the product rule, the **9:3:3:1** ratio of a dihybrid cross can be predicted because we can consider each trait separately.

RrYy X RrYy

R_Y_  = ¾ X ¾ = 9/16 **9**

rrY_  = ¼ X ¾ = 3/16 **3**

R_yy  = ¾ X ¼ = 3/16 **3**

yyrr  = ¼ X ¼ = 1/16 **1**

	R	r
R	RR	Rr
r	Rr	rr

	Y	y
Y	YY	Yy
y	Yy	yy

➢ What is the probability of finding a zygote of RRYY genotype in the cross RrYy X RrYy?

1. What is the probability of getting RR?

1/4

	R	r
R	RR	Rr
r	Rr	rr

2. What is the probability of getting YY?

1/4

	Y	y
Y	YY	Yy
y	Yy	yy

Thus, the probability of RRYY (RR and YY) =

1/4 X 1/4 = 1/16

- **What is the probability of obtaining a round, green seed from a dihybrid (RrYy) cross?**

	R	r
R	RR	Rr
r	Rr	rr

	Y	y
Y	YY	Yy
y	Yy	yy

- Genotype can be either **RRyy** or **Rryy**

→ R_yy

✓ p(R_ and yy) = p(R_) and p(yy) **(product rule)**

¾ ¼

= ¾ X ¼ = 3/16 R_yy

- **What fraction of the progeny from the following cross will have large, smooth, purple fruit?**

LlSsPp x LlssPP

Texture	Color	Size
S - smooth	P – purple	L – large
s - rough	p – pink	l – small

large: p(LL or Ll) = 1/4 + 2/4 = 3/4

smooth: p(Ss) = 1/2

purple: p(Pp or PP) = all = 1

	L	l
L	LL	Ll
l	Ll	ll

	s	s
S	Ss	Ss
s	ss	ss

	P	P
P	PP	PP
p	Pp	Pp

✓ large, smooth, purple: **p(L_S_P_) = ½ X 1 X ¾ = 3/8**

Laws of probability for multiple genes

P RRYYTTSS × rryyttss

F1 RrYyTtSs × RrYyTtSs

What is the probability of obtaining the genotype RrYyTtss?

Rr × Rr	Yy X Yy	Tt × Tt	Ss × Ss
1RR:2Rr:1rr	1YY:2Yy:1yy	1TT:2Tt:1tt	1SS:2Ss:1ss
2/4 Rr	2/4 Yy	2/4 Tt	1/4 ss

Probability of obtaining individual with Rr **and** Yy **and** Tt **and** ss.
(probability of events occurring together)

$2/4 \times 2/4 \times 2/4 \times 1/4 = 8/256$ (or 1/32)

Laws of probability for multiple genes

P RRYYTTSS × rryyttss

F1 RrYyTtSs × RrYyTtSs

What is the probability of obtaining a completely homozygous genotype? (probability of either/or events occurring)

Genotype could be RRYYTTSS **or** rryyttss

Rr × Rr	Yy × Yy	Tt × Tt	Ss × Ss
1RR:2Rr:1rr	1YY:2Yy:1yy	1TT:2Tt:1tt	1SS:2Ss:1ss
1/4 RR 1/4 rr	1/4 YY 1/4 yy	1/4 TT 1/4 tt	1/4 SS 1/4 ss

$(1/4 \times 1/4 \times 1/4 \times 1/4) + (1/4 \times 1/4 \times 1/4 \times 1/4) = 2/256$

Probability of homo Dom + probability of homo Rec)

Question

- If we cross RrYyTtSs × RrYyTtSs, what is the probability of obtaining the genotype RRYyTtss?
-
  - 1) 1/16
  - 2) 1/32
  - 3) 1/64
  - 4) 1/128

Question

- If we cross RrYyTtSs × RrYyTtSs, what is the probability of obtaining the genotype RRYyTtss or RRYyTtSS?
-
  - 1) 1/16
  - 2) 1/32
  - 3) 1/64
  - 4) 1/128

Probability -- conclusions

- Probability can be used to predict the types of progeny that will result from a monohybrid or dihybrid cross
- The Punnett square is a graphical representation of these possible outcomes
- Phenotypes are the result of the genotype of an organism
  - more than one genotype may result in the same phenotype
- Distinct segregation patterns result from monohybrid, dihybrid, and test-crosses

Homework Problems

- Chapter 2
- # 2, 12, 16, 17, 21
- DON’T forget to submit the iActivity “Tribble Traits”