## 📄 Cheat Sheet 1 – Gene Interaction (Definition & Types) 🧬

### 🔶 Definition

- **Gene interaction** = when two or more **non-allelic genes** influence a single trait.
- Modifies the typical **Mendelian ratios (3:1, 9:3:3:1)** into altered ratios.
- Explains why many traits don't follow simple Mendelian laws.

---

### 🔶 Types of Gene Interactions

1. **Complementary Genes**
   - Two genes together produce a new trait.
   - Ratio = **9:7**.
   - Example: Flower color in **sweet pea (Lathyrus odoratus)**.
2. **Epistasis**
   - One gene masks/modifies the effect of another non-allelic gene.
   - **Recessive epistasis** (9:3:4) – e.g., coat color in mice.
   - **Dominant epistasis** (12:3:1) – e.g., fruit color in summer squash.
3. **Duplicate Genes**
   - Either gene alone can produce the trait.
   - Ratio = **15:1**.
   - Example: Leaf shape in **shepherd's purse (Capsella bursa-pastoris)**.
4. **Duplicate Genes with Cumulative Effect**
   - Two genes contribute additively.
   - Ratio = **9:6:1**.
   - Example: Grain color in wheat.
5. **Polymeric Gene Interaction**
   - More than one gene produces a **similar phenotype** with cumulative effect.
6. **Modifier & Suppressor Genes**
   - **Modifier genes** → alter the effect of other genes quantitatively.
   - **Suppressor genes** → inhibit expression of another gene.

---

### 🔶 Key Ratios (Non-Mendelian)

- Complementary → **9:7**
- Recessive Epistasis → **9:3:4**

- Dominant Epistasis → **12:3:1**
- Duplicate → **15:1**
- Duplicate with cumulative effect → **9:6:1**

---

### 💠 Mnemonics 💡

- **"Cool Elephants Don't Dance Properly"** 🐘
  - **C**omplementary (9:7)
  - **E**pistasis (9:3:4 / 12:3:1)
  - **D**uplicate (15:1)
  - **D**uplicate cumulative (9:6:1)
  - **P**olymeric

---

### 💠 Exam Capsule 🎯

- Gene interaction = non-allelic genes modifying a trait.
- Produces **modified ratios** (9:7, 12:3:1, 9:3:4, 15:1, 9:6:1).
- Includes complementary genes, epistasis, duplicate genes, polymeric effects, and modifiers.

---

## 📄 Cheat Sheet 2 – Complementary Gene Interaction (9:7 Ratio) 🌸▯

### 💠 Definition

- **Complementary gene interaction** occurs when **two different non-allelic dominant genes** are required together to produce a particular trait.
- If either gene is absent (homozygous recessive), the trait is not expressed.

---

### 💠 Classic Example: Flower Color in Sweet Pea (*Lathyrus odoratus*)

- Two genes: **C** and **P**.
- **C** = provides substrate; **P** = provides enzyme to convert it into pigment.
- Presence of both dominant alleles (**C_P_**) → purple flowers.
- Any recessive combination (ccP_, C_pp, ccpp) → white flowers.

---

### 💠 $F_2$ Cross (CcPp × CcPp)

- Gametes: CP, Cp, cP, cp.
- Resulting phenotypes:

| Combination | Phenotype |
| --- | --- |
| C_P_ (9) | Purple flowers |
| ccP_, C_pp, ccpp (7) | White flowers |

- **Phenotypic ratio = 9 Purple : 7 White**

---

### 💠 Key Features

- Both genes are **essential** for trait expression.
- Lack of one gene → metabolic block → no pigment.
- Example of **complementary action**.

---

### 💠 Other Examples

- **Kernel color in maize**.
- **Fruit shape in gourds**.

---

### 💠 Mnemonics 💡

- **Complementary = "Both Needed"** → like pen & ink together to write.

---

### 💠 Exam Capsule 🎯

- Complementary genes = **two dominant alleles required together** for expression.
- Ratio = **9:7** in $F_2$ generation.
- Example: Purple flower in sweet pea requires **C & P** genes.

## 📄 Cheat Sheet 3 – Epistasis (Dominant & Recessive) ▯🎨

### 💠 Definition

- **Epistasis** = interaction where one gene **masks or modifies** the expression of another non-allelic gene.
- The masking gene = **epistatic**; the gene being masked = **hypostatic**.

---

### 🔷 1. Recessive Epistasis (9:3:4 ratio)

- Trait expression masked when one gene is **homozygous recessive**.
- Example: **Coat color in mice**
  - Gene C = pigment production, Gene A = pigment distribution.
  - **C_A_ → agouti**
  - **ccA_ or ccnn → albino (no pigment)**
  - **C_aa → black**
  - Ratio = **9 agouti : 3 black : 4 albino**

---

### 🔷 2. Dominant Epistasis (12:3:1 ratio)

- A single **dominant allele** of one gene masks the expression of another.
- Example: **Fruit color in summer squash**
  - Gene W = inhibits pigment (white color, epistatic).
  - Gene Y = yellow pigment if ww.
  - **W_ _ → white**
  - **wwY_ → yellow**
  - **wwyy → green**
  - Ratio = **12 white : 3 yellow : 1 green**

---

### 🔷 Key Points

- Epistasis modifies **classical Mendelian dihybrid ratio (9:3:3:1)**.
- Types:
  - Recessive epistasis (9:3:4)
  - Dominant epistasis (12:3:1)
  - Other modified ratios also possible (13:3, 15:1 etc.).

---

### 🔷 Mnemonics 💡

- **Recessive Epistasis = "4 whites"** (9:3:4).
- **Dominant Epistasis = "Dozen whites"** (12:3:1).

---

### 🔷 Exam Capsule 🎯

- Epistasis = one gene masks another.

- Recessive epistasis → 9:3:4 (mice coat color).
- Dominant epistasis → 12:3:1 (squash fruit color).
- Shows gene interaction beyond simple dominance.

## 📄 Cheat Sheet 4 – Duplicate Genes with Cumulative Effect (9:6:1 Ratio) 🌾🎨

### 🔹 Definition

- **Duplicate genes with cumulative effect** = when two non-allelic dominant genes contribute **additively** to a trait.
- Presence of **both dominants** gives a distinct phenotype; presence of only one gives an intermediate; absence of both gives another phenotype.

---

### 🔹 Classic Example: Grain Color in Wheat 🌾

- Genes: **A** and **B**.
- **A_B_** → **dark red** (both dominants contribute → cumulative).
- **A_bb or aaB_** → **light red** (one dominant present).
- **aabb** → **white** (no dominant alleles).

---

### 🔹 $F_2$ Cross (AaBb × AaBb)

- Phenotypes:
    - 9 A_B_ → Dark Red
    - 6 A_bb or aaB_ → Light Red
    - 1 aabb → White
- **Phenotypic ratio = 9:6:1**

---

### 🔹 Key Features

- Both dominant genes act **independently but additively**.
- Intermediate phenotype appears when only one dominant is present.
- Example of **quantitative modification**.

---

### 🔹 Other Examples

- Fruit shape in gourds.

- Kernel color in maize (similar cumulative effect).

---

### ◈ Mnemonics 💡

- **"Duplicate + Together = Strong (Dark)"**
- Both dominants → strong effect (dark red).
- One dominant → weaker effect (light red).
- None → no effect (white).

---

### ◈ Exam Capsule 🎯

- Duplicate genes with cumulative effect = **two genes contribute additively**.
- Ratio = **9:6:1**.
- Example: **Wheat grain color** (dark red, light red, white).
- Shows **quantitative gene interaction**.

## 📄 Cheat Sheet 5 – Duplicate Genes without Cumulative Effect (15:1 Ratio) 🌱

### ◈ Definition

- **Duplicate genes without cumulative effect** = when two different non-allelic dominant genes produce the **same phenotype independently**.
- Presence of either dominant is enough; both together do not enhance the effect.

---

### ◈ Classic Example: Capsella (Shepherd's Purse) Seed Shape

- Genes: **A** and **B**.
- **A_B_ → triangular seeds**.
- **A_bb → triangular seeds**.
- **aaB_ → triangular seeds**.
- **aabb → ovoid seeds**.

---

### ◈ $F_2$ Cross (AaBb × AaBb)

- Phenotypes:
  - 15 triangular (A_B_, A_bb, aaB_)
  - 1 ovoid (aabb)

- **Phenotypic ratio = 15:1**

---

### 💠 Key Features

- Either dominant allele alone produces same trait.
- Double dominant does not change or add to phenotype.
- Only when **both genes recessive** → alternate phenotype appears.

---

### 💠 Other Examples

- Fruit shape in gourds.
- Resistance to certain plant pathogens.

---

### 💠 Mnemonics 💡

- **Duplicate = "One is enough"** → 15 dominants vs 1 recessive.

---

### 💠 Exam Capsule 🎯

- Duplicate genes without cumulative effect = **dominant alleles produce same phenotype**.
- Ratio = **15:1** in $F_2$ .
- Example: **Shepherd's purse seed shape** (triangular vs ovoid).
- Shows **functional redundancy** in genes.

## 📄 Cheat Sheet 6 – Polymeric Gene Interaction ▯

### 💠 Definition

- **Polymeric interaction** occurs when **two or more non-allelic dominant genes** influence the **same trait in a similar way**.
- The combined effect of genes is **greater than their individual effects**.
- Often contributes to **quantitative inheritance**.

---

### 💠 Example: Fruit Shape in Cucurbits (Gourds)

- Genes: **A** and **B**.
- **A_B_ → disc-shaped fruit** (new phenotype due to polymeric effect).
- **A_bb or aaB_ → spherical fruit**.
- **aabb → long fruit**.

---

### 💠 $F_2$ Cross (AaBb × AaBb)

- Phenotypic ratio = **9 disc : 6 spherical : 1 long**

---

### 💠 Features

- Interaction of genes gives rise to a **novel phenotype**.
- Both genes act **synergistically** to modify expression.
- Distinct from duplicate/cumulative because it produces a **new trait**, not just enhanced intensity.

---

### 💠 Other Examples

- Kernel texture in maize.
- Some cases of flower color modification.

---

### 💠 Mnemonics 💡

- **Polymeric = "Partners Produce a Phenotype"** → both dominants together = new trait.

---

### 💠 Exam Capsule 🎯

- Polymeric interaction = genes act together to produce **new phenotype**.
- Ratio = **9:6:1** (disc, spherical, long fruits in gourds).
- Shows **synergistic gene action**.

## 📄 Cheat Sheet 7 – Pleiotropy (One Gene → Multiple Effects) ▯

### 💠 Definition

- **Pleiotropy** = condition where **one gene influences multiple traits**.
- Opposite of polygenic inheritance (where many genes control one trait).

---

🔷 **Key Examples**

1. **Sickle-Cell Anemia (Humans)**

- Mutation in β-globin gene → abnormal hemoglobin (HbS).
- Multiple effects:
  - Sickled RBC shape.
  - Anemia due to hemolysis.
  - Resistance to malaria.
- Single mutation affects **blood morphology, physiology, and disease resistance**.

2. **Phenylketonuria (PKU)**

- Mutation in gene encoding enzyme phenylalanine hydroxylase.
- Multiple effects:
  - Accumulation of phenylalanine → mental retardation.
  - Light skin/hair (reduced melanin).
  - Neurological issues.

3. **Marfan Syndrome**

- Mutation in fibrillin-1 gene.
- Effects: long limbs, lens dislocation, cardiovascular abnormalities.

---

🔷 **Features**

- One gene → multiple, often unrelated phenotypes.
- Seen in both **plants and animals**.
- Important in human genetic diseases.

---

🔷 **Mnemonics** 💡

- **Pleiotropy = "Plenty of Traits from One Gene"**.

---

🔷 **Exam Capsule** 🎯

- Pleiotropy = one gene → multiple effects.
- Examples: **Sickle-cell anemia, PKU, Marfan syndrome**.
- Contrast: **Polygenic inheritance = many genes → one trait**.

📄 **Cheat Sheet 8 – Lethal Genes (2:1 Ratio) ☠️▯**

## 🔷 Definition

- **Lethal genes** = genes that cause **death of the organism** when present in certain genotypes.
- May be **dominant** or **recessive**.
- Alter normal Mendelian ratios (e.g., 3:1 → 2:1).

---

## 🔷 Types

1. **Recessive Lethal Genes**

- Cause death only in **homozygous recessive condition**.
- Example: **Yellow coat in mice (AY allele)**
  - Cross: AY A × AY A →
  - AY AY = lethal (death).
  - AY A = yellow.
  - AA = agouti.
  - Ratio: **2 yellow : 1 agouti** (not 3:1).

2. **Dominant Lethal Genes**

- Cause death even in heterozygous condition.
- Rare, as they are usually eliminated from populations.
- Example: **Huntington's disease in humans** (late onset → persists).

---

## 🔷 Other Examples

- **Manx cat**: tailless condition due to lethal homozygous state.
- **Creeper fowl**: homozygotes die; heterozygotes show short legs.

---

## 🔷 Key Features

- Lethal genes distort expected Mendelian ratios.
- Can be embryonic lethal → death before birth.
- Help explain absence of certain genotypes in offspring.

---

## 🔷 Mnemonics 💡

- **Lethal = "Lost in Ratio"** → 3:1 changes to 2:1.

---

### 🔶 Exam Capsule 🎯

- Lethal genes cause organism death in specific genotypes.
- **Recessive lethal** → **2:1 ratio** (mice coat color).
- **Dominant lethal** → rare, e.g., Huntington's disease.
- Seen in mice, cats, fowls, humans.

## 📄 Cheat Sheet 9 – Modifier & Suppressor Genes ▯▯

### 🔶 Definition

- Genes that **modify or suppress the expression** of other genes without being allelic.
- Important in **fine-tuning traits** and in explaining non-Mendelian inheritance.

---

### 🔶 1. Modifier Genes

- Alter the **quantitative effect** of another gene.
- Do not mask completely but **increase or decrease intensity** of expression.
- Example: **Skin color in humans**
    - Multiple modifying genes influence degree of pigmentation.
- Example: In mice, modifier genes alter coat color intensity.

---

### 🔶 2. Suppressor Genes

- Genes that **inhibit or silence** the effect of another gene.
- Can restore normal phenotype by suppressing a mutant gene.
- Example: In *Drosophila*, suppressor genes can silence mutations affecting eye color.
- Example: In humans, some suppressor genes control oncogenes → preventing cancer.

---

### 🔶 Key Features

- Both act in **gene interaction** but in different ways:
    - **Modifier** = "volume control" (adjust intensity).
    - **Suppressor** = "mute button" (turn off expression).

### 💠 Significance

- Explain variable expressivity of traits.
- Important in **genetic diseases, cancer biology, evolution**.
- Provide buffering against harmful mutations.

---

### 💠 Mnemonics 💡

- **Modifier = “More or Less”**
- **Suppressor = “Stop Signal”**

---

### 💠 Exam Capsule 🎯

- Modifier genes → alter effect of another gene quantitatively.
- Suppressor genes → inhibit the action of another gene.
- Both explain deviations from Mendelian ratios.
- Important in **phenotypic variation & disease regulation**.

## 📄 Cheat Sheet 10 – Cytoplasmic Inheritance (Extranuclear / Maternal Inheritance) 🌱⚡

### 💠 Definition

- **Cytoplasmic inheritance** = transmission of traits through **DNA present in organelles** (mitochondria, chloroplasts) rather than nuclear genes.
- Also called **extranuclear inheritance** or **maternal inheritance**.

---

### 💠 Key Features

- DNA found in **mitochondria & chloroplasts** (mtDNA, cpDNA).
- Inherited **maternally** in most organisms (zygote cytoplasm from egg).
- Follows **non-Mendelian ratios**.
- Mutations in these organelles can affect energy metabolism & pigmentation.

---

### 🔷 Examples

1. **Leaf Variegation in *Mirabilis jalapa* (Four o'clock plant)**

- Green leaves → normal chloroplasts.
- White leaves → defective chloroplasts.
- Variegated leaves → mixture.
- Inheritance depends on cytoplasm of ovule (maternal).

2. **Male Sterility in Plants (CMS – Cytoplasmic Male Sterility)**

- Important in hybrid seed production.
- Controlled by mitochondrial genes.

3. **Mitochondrial Diseases in Humans**

- Leber's Hereditary Optic Neuropathy (LHON).
- Kearns–Sayre syndrome.
- All inherited maternally.

---

### 🔷 Significance

- Explains inheritance patterns not fitting Mendelian laws.
- Critical in **plant breeding (hybrid production)**.
- Helps understand **human metabolic diseases**.
- Basis of mitochondrial genetics in evolution (endosymbiotic theory).

---

### 🔷 Mnemonics 💡

- **Cytoplasmic inheritance = "Comes from the Mother"** 👩

---

### 🔷 Exam Capsule 🎯

- Traits inherited via **mitochondrial & chloroplast DNA**.
- Maternally inherited (egg cytoplasm).
- Examples: Leaf variegation in *Mirabilis*, CMS in plants, human mitochondrial diseases.
- Explains **non-Mendelian inheritance**.

## 📄 Cheat Sheet 11 – Extra Non-Mendelian Ratios (Modified Mendelian Ratios) 🔢🌱

### 🔶 Introduction

- In classical Mendelian genetics, dihybrid cross produces **9:3:3:1 ratio**.
- Gene interactions modify this into **non-Mendelian ratios** like 9:7, 12:3:1, 9:3:4, 15:1, etc.
- Some special ratios are also observed.

---

### 🔶 Examples of Modified Ratios

1. **13:3 Ratio –** Suppressor Gene Action

- One gene suppresses the expression of another.
- Example: **Feather color in fowl**.
  - Dominant allele at one locus suppresses pigment production.
  - Phenotypic ratio: 13 white : 3 colored.

---

2. **9:6:1 Ratio –** Cumulative Effect (already discussed in wheat kernel color)

- Two genes contribute additively → intermediate phenotype appears when only one gene is active.
- Example: **Fruit shape in gourds** → disc : spherical : long.

---

3. **9:3:3:1 (Mendel's original dihybrid ratio)**

- Still observed when no gene interaction is present.
- Serves as baseline to identify modifications.

---

4. **Other Ratios**

- **9:6:1** → **cumulative interaction** (wheat color).
- **9:3:4** → **recessive epistasis** (mice coat color).
- **12:3:1** → **dominant epistasis** (squash color).
- **15:1** → **duplicate genes** (shepherd's purse).

---

### 🔶 Significance

- These ratios demonstrate **gene interactions beyond Mendelian laws**.
- Crucial in plant/animal breeding to predict unexpected outcomes.

- Show that multiple genes often work **in networks, not isolation**.

---

## 🔷 Mnemonics 💡

- **"Funny Ratios Tell Genetic Stories"** 🐭
  - 13:3 = Suppressor
  - 9:6:1 = Cumulative
  - 12:3:1 = Dominant Epistasis
  - 9:3:4 = Recessive Epistasis
  - 15:1 = Duplicate

---

## 🔷 Exam Capsule 🎯

- Modified ratios arise due to **gene interactions**.
- 13:3 (suppressor genes, fowl feather color).
- 9:6:1 (cumulative, gourds/wheat).
- Classical 9:3:3:1 = baseline.
- Ratios are key evidence for **non-Mendelian inheritance patterns**.