

# Calculus III Running Notes

## Points of Interest in Multivariable Functions

**Finding POE's:**  $\nabla f(x,y,z)$  at  $(x_0, y_0, z_0)$   
 Find  $D = f_{xx} \cdot f_{yy} - (f_{xy})^2$   
**Case 1:**  $D > 0, f_{xx} > 0, f(x,y) \rightarrow$  local min  
**Case 2:**  $D > 0, f_{xx} < 0, f(x,y) \rightarrow$  local max  
**Case 3:**  $D < 0, f(x,y) \rightarrow$  neither.  $P(x,y)$  is saddle point, "if  $D$  is negative" and the graph crosses the tangent plane at  $(x,y)$   
**Case 4:** if  $D = 0$ , no information is given. The point  $(x,y)$  can be a local min, local max or a saddle point

## Lagrange Multipliers

$\nabla f(x,y,z) = \lambda \nabla g(x,y,z)$      $g(x,y,z) = k$   
 $f_x = \lambda g_x$      $f_y = \lambda g_y$      $f_z = \lambda g_z$

## Triple Integrals

if  $f$  is continuous for the rectangular box  $B = [a,b] \times [c,d] \times [e,f]$ , then  
 $\iiint_B f(x,y,z) \, dV = \int_a^b \int_c^d \int_e^f f(x,y,z) \, dz \, dy \, dx$   
**Type I plane region:**  
 $\iiint f(x,y,z) \, dV = \int_a^b \int_c^d \int_{g_1(x,y)}^{g_2(x,y)} f(x,y,z) \, dz \, dy \, dx$   
**Type II region:**  
 $\iiint f(x,y,z) \, dV = \int_c^d \int_a^b \int_{g_1(y,z)}^{g_2(y,z)} f(x,y,z) \, dx \, dy \, dz$

## Double Integrals Over Rectangles

$R = [a,b] \times [c,d] = \{(x,y) \in \mathbb{R}^2 \mid a \leq x \leq b, c \leq y \leq d\}$   
 $S = \{(x,y,z) \in \mathbb{R}^3 \mid 0 \leq z \leq f(x,y), (x,y) \in R\}$   
**Definition:**  
 $\iint_R f(x,y) \, dA = \lim_{n \rightarrow \infty} \sum_{i=1}^n \sum_{j=1}^m f(x_i^*, y_j^*) \Delta A$

## Double Integrals over General Regions

**Type I:**  
 $D = \{(x,y) \mid a \leq x \leq b, g_1(x) \leq y \leq g_2(x)\}$   
 $\iint_D f(x,y) \, dA = \int_a^b \int_{g_1(x)}^{g_2(x)} f(x,y) \, dy \, dx$   
**Type II:**  
 $D = \{(x,y) \mid c \leq y \leq d, h_1(y) \leq x \leq h_2(y)\}$   
 $\iint_D f(x,y) \, dA = \int_c^d \int_{h_1(y)}^{h_2(y)} f(x,y) \, dx \, dy$

## Triple integrals in Cylindrical Co-ordinates

**Cylindrical coordinate system:**  
 $x = r \cos \theta$      $y = r \sin \theta$      $z = z$   
**Rectangular to cylindrical coordinates:**  
 $r = \sqrt{x^2 + y^2}$      $\theta = \arctan \frac{y}{x}$      $z = z$   
**Combining with Triple Integral Equations:**  
 $\iiint f(x,y,z) \, dV = \int_a^b \int_c^d \int_{g_1(r,\theta)}^{g_2(r,\theta)} f(r \cos \theta, r \sin \theta, z) \, r \, dz \, dr \, d\theta$

## Double Integrals in Polar Co-ordinates

$\iint_R f(x,y) \, dA = \iint_D f(r \cos \theta, r \sin \theta) \, r \, dr \, d\theta$   
 $(r \cos \theta)^2 + (r \sin \theta)^2 = r^2$   
 $= r^2 \cos^2 \theta + r^2 \sin^2 \theta = r^2 (\cos^2 \theta + \sin^2 \theta) = r^2$

## Triple integrals in Spherical Co-ordinates

$\rho =$  rho (radius)     $\phi =$  phi (polar angle)     $\theta =$  theta (azimuthal angle)  
**Distance formula:**  
 $\rho^2 = x^2 + y^2 + z^2$   
**In triple integral formula:**  
 $\iiint f(x,y,z) \, dV = \int_a^b \int_c^d \int_{g_1(\rho,\theta,\phi)}^{g_2(\rho,\theta,\phi)} f(\rho \sin \phi \cos \theta, \rho \sin \phi \sin \theta, \rho \cos \phi) \, \rho^2 \sin \phi \, d\rho \, d\theta \, d\phi$

### Iterated Integrals

$\int_a^b \int_c^d f(x,y) \, dy \, dx$

### Fubini's Theorem:

if  $R = \{(x,y) \mid a \leq x \leq b, c \leq y \leq d\}$  — must be continuous rectangle!

Then:  $\iint_R f(x,y) \, dA = \int_a^b \int_c^d f(x,y) \, dy \, dx = \int_c^d \int_a^b f(x,y) \, dx \, dy$

### Special Case:

$\iint_R xy \, dA = \int_a^b \int_c^d xy \, dy \, dx$  where  $R = [a,b] \times [c,d]$

### Average value:

$f_{avg} = \frac{1}{A} \iint_R f(x,y) \, dA$

## Applications of Double Integrals

$\rho(x,y) =$  mass per unit area  
 $M = \iint_R \rho(x,y) \, dA$   
 $\bar{x} = \frac{1}{M} \iint_R x \rho(x,y) \, dA$      $\bar{y} = \frac{1}{M} \iint_R y \rho(x,y) \, dA$   
**Centroid:**  $(\bar{x}, \bar{y}) = \left( \frac{1}{A} \iint_R x \, dA, \frac{1}{A} \iint_R y \, dA \right)$

## Surface Area:

$A(S) = \iint_R \sqrt{f_x^2 + f_y^2 + 1} \, dA$

## Line Integrals (Cont)

with respect to Arc Length:  
 $\int_C f(x,y,z) \, ds = \int_a^b f(x(t), y(t), z(t)) \sqrt{x'(t)^2 + y'(t)^2 + z'(t)^2} \, dt$   
 $W = \int_C f(x,y,z) \, ds = \int_a^b f(x(t), y(t), z(t)) \sqrt{x'(t)^2 + y'(t)^2 + z'(t)^2} \, dt$   
 $W = \int_a^b [F(x(t), y(t), z(t))] \sqrt{x'(t)^2 + y'(t)^2 + z'(t)^2} \, dt$   
 $W = \int_a^b F(t) \sqrt{x'(t)^2 + y'(t)^2 + z'(t)^2} \, dt$

## Line Integrals:

If  $f$  is defined on a smooth curve  $C$  given by  $x = x(t), y = y(t), z = z(t), a \leq t \leq b$ . Then the line integral along  $C$  is:  
 $\int_C f(x,y,z) \, ds = \int_a^b f(x(t), y(t), z(t)) \sqrt{x'(t)^2 + y'(t)^2 + z'(t)^2} \, dt$   
**Line integral with respect to Arc Length:**  
 $\int_C f(x,y) \, ds = \int_a^b f(x(t), y(t)) \sqrt{x'(t)^2 + y'(t)^2} \, dt$   
 $\int_C f(x,y) \, dy = \int_a^b f(x(t), y(t)) y'(t) \, dt$   
**Vector representation of a line segment that starts at  $(x_1, y_1)$  and ends at  $(x_2, y_2)$  is given by:**  
 $\mathbf{r}(t) = (x_2 - x_1)t + (y_2 - y_1)t + (x_1, y_1)$      $0 \leq t \leq 1$   
 $\int_C f(x,y) \, ds = \int_a^b f(x(t), y(t)) \sqrt{x'(t)^2 + y'(t)^2} \, dt$

## Green's Theorem:

Let  $C$  be a positively oriented, piecewise smooth, simple closed curve in the plane  $D$  bounded by  $C$ . If  $P$  and  $Q$  have continuous partial derivatives on an open region that contains  $D$ , then:  
 $\int_C P \, dx + Q \, dy = \iint_D \left( \frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y} \right) \, dA$   
**In a simple region:**  
 $\int_C P \, dx = - \iint_D \frac{\partial P}{\partial y} \, dA$   
 $\int_C Q \, dy = \iint_D \frac{\partial Q}{\partial x} \, dA$   
 for a counter (topology) a circle:  
 $A = \oint_C x \, dy = - \oint_C y \, dx = \frac{1}{2} \oint_C x \, dy - y \, dx$   
**Extends:**  
 $\int_C P \, dx + Q \, dy = \iint_D \left( \frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y} \right) \, dA$

## Fundamental Theorem of Line Integrals

if  $\mathbf{F}(x,y,z) = \nabla \phi(x,y,z)$  is a conservative vector field:  
 $\frac{\partial \phi}{\partial x} = P$      $\frac{\partial \phi}{\partial y} = Q$      $\frac{\partial \phi}{\partial z} = R$   
 $\int_C \mathbf{F} \cdot d\mathbf{r} = \phi(\mathbf{r}(b)) - \phi(\mathbf{r}(a))$

## Vector Fields

A vector field is a function that maps points to vectors.  
**In  $\mathbb{R}^2$  (plane):**  
 $\mathbf{F}(x,y) = P(x,y)\mathbf{i} + Q(x,y)\mathbf{j} = \langle P, Q \rangle$   
**In  $\mathbb{R}^3$  (space):**  
 $\mathbf{F}(x,y,z) = P(x,y,z)\mathbf{i} + Q(x,y,z)\mathbf{j} + R(x,y,z)\mathbf{k} = \langle P, Q, R \rangle$

## Curl and Divergence

For  $\mathbf{F} = P\mathbf{i} + Q\mathbf{j} + R\mathbf{k}$ :  
 $\text{curl } \mathbf{F} = \left( \frac{\partial R}{\partial y} - \frac{\partial Q}{\partial z} \right) \mathbf{i} + \left( \frac{\partial P}{\partial z} - \frac{\partial R}{\partial x} \right) \mathbf{j} + \left( \frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y} \right) \mathbf{k}$   
 $\nabla \cdot \mathbf{F} = \left( \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} + \frac{\partial R}{\partial z} \right)$   
 and  $\text{curl } \mathbf{F} = \nabla \times \mathbf{F}$   
**If  $F$  is a function of 3 variables that has continuous second order partial derivatives then:**  
 $\text{curl } (\nabla F) = \mathbf{0}$   
 $\text{div } (\nabla \times \mathbf{F}) = \mathbf{0}$   
 $\nabla \cdot (\nabla \cdot \mathbf{F}) = \nabla^2 F = \Delta F$

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**D Kirk**



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