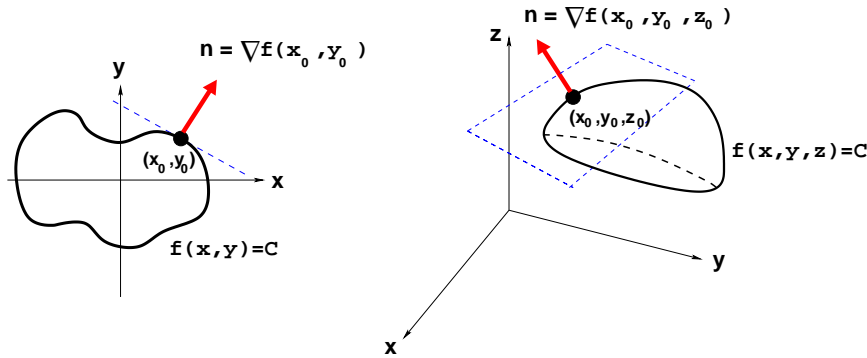


Study Guide # 2

0. Gradient vector for $f(x, y)$: $\nabla f(x, y) = \left\langle \frac{\partial f}{\partial x}, \frac{\partial f}{\partial y} \right\rangle$, properties of gradients; gradient points in direction of maximum rate of increase of f ; The maximum value of the directional derivative is equal to $\|\nabla f\|$; $\nabla f(x_0, y_0) \perp$ level curve $f(x, y) = C$ and, in the case of 3 variables, $\nabla f(x_0, y_0, z_0) \perp$ level surface $f(x, y, z) = C$:



1. Relative/local extrema; critical points ($\nabla f = \vec{0}$ or ∇f does not exist); 2^{nd} Derivatives Test: A critical points is a local min if $D = f_{xx}f_{yy} - f_{xy}^2 > 0$ and $f_{xx} > 0$, local max if $D > 0$ and $f_{xx} < 0$, saddle if $D < 0$; absolute extrema; Max-Min Problems; **Lagrange Multipliers:** Extremize $f(\vec{x})$ subject to a constraint $g(\vec{x}) = C$, solve the system: $\nabla f = \lambda \nabla g$ and $g(\vec{x}) = C$.

2. Double integrals; Midpoint Rule for rectangle : $\iint_R f(x, y) dA \approx \sum_{i=1}^m \sum_{j=1}^n f(\bar{x}_i, \bar{y}_j) \Delta A$;

3. Type I region $D : \begin{cases} g_1(x) \leq y \leq g_2(x) \\ a \leq x \leq b \end{cases}$; Type II region $D : \begin{cases} h_1(y) \leq x \leq h_2(y) \\ c \leq y \leq d \end{cases}$;

iterated integrals over Type I and II regions: $\iint_D f(x, y) dA = \int_a^b \int_{g_1(x)}^{g_2(x)} f(x, y) dy dx$ and

$\iint_D f(x, y) dA = \int_c^d \int_{h_1(y)}^{h_2(y)} f(x, y) dx dy$, respectively; Reversing Order of Integration (regions that are both Type I and Type II); properties of double integrals.

4. Integral inequalities: $mA \leq \iint_D f(x, y) dA \leq MA$, where $A =$ area of D and $m \leq f(x, y) \leq M$ on D .

5. Change of Variables Formula in Polar Coordinates: if $D : \begin{cases} h_1(\theta) \leq r \leq h_2(\theta) \\ \alpha \leq \theta \leq \beta \end{cases}$, then

$$\iint_D f(x, y) dA = \int_{\alpha}^{\beta} \int_{h_1(\theta)}^{h_2(\theta)} f(r \cos \theta, r \sin \theta) r dr d\theta.$$

↑

6. Applications of double integrals:

(a) Area of region D is $A(D) = \iint_D dA$

(b) Volume of solid under graph of $z = f(x, y)$, where $f(x, y) \geq 0$, is $V = \iint_D f(x, y) dA$

(c) Mass of D is $m = \iint_D \rho(x, y) dA$, where $\rho(x, y) =$ density (per unit area); sometimes write $m = \iint_D dm$, where $dm = \rho(x, y) dA$.

(d) Moment about the x -axis $M_x = \iint_D y \rho(x, y) dA$; moment about the y -axis $M_y = \iint_D x \rho(x, y) dA$.

(e) Center of mass (\bar{x}, \bar{y}) , where $\bar{x} = \frac{M_y}{m} = \frac{\iint_D x \rho(x, y) dA}{\iint_D \rho(x, y) dA}$, $\bar{y} = \frac{M_x}{m} = \frac{\iint_D y \rho(x, y) dA}{\iint_D \rho(x, y) dA}$

Remark: centroid = center of mass when density is constant (this is useful).

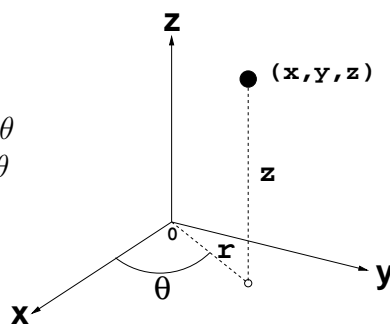
7. Elementary solids $E \subset \mathbb{R}^3$ of Type 1, Type 2, Type 3; triple integrals over solids E :

$$\iiint_E f(x, y, z) dV = \iint_D \int_{u(x,y)}^{v(x,y)} f(x, y, z) dz dA \text{ for } E = \{(x, y) \in D, u(x, y) \leq z \leq v(x, y)\};$$

volume of solid E is $V(E) = \iiint_E dV$; applications of triple integrals, mass of a solid, moments about the coordinate planes M_{xy}, M_{xz}, M_{yz} , center of mass of a solid $(\bar{x}, \bar{y}, \bar{z})$.

8. Cylindrical Coordinates (r, θ, z) :

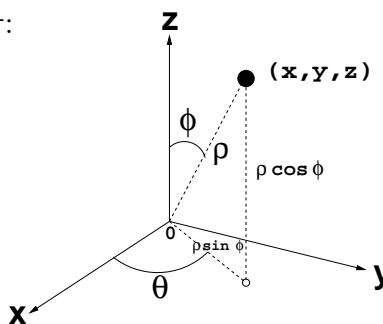
From CC to RC :
$$\begin{cases} x = r \cos \theta \\ y = r \sin \theta \\ z = z \end{cases}$$



Going from RC to CC use $x^2 + y^2 = r^2$ and $\tan \theta = \frac{y}{x}$ (make sure θ is in correct quadrant).

9. Spherical Coordinates (ρ, θ, ϕ) , where $0 \leq \phi \leq \pi$:

From SC to RC :
$$\begin{cases} x = (\rho \sin \phi) \cos \theta \\ y = (\rho \sin \phi) \sin \theta \\ z = \rho \cos \phi \end{cases}$$



Going from RC to SC use $x^2 + y^2 + z^2 = \rho^2$, $\tan \theta = \frac{y}{x}$ and $\cos \phi = \frac{z}{\rho}$.

10. Triple integrals in Cylindrical Coordinates: $\begin{cases} x = r \cos \theta \\ y = r \sin \theta \\ z = z \end{cases}, \quad dV = r \, dz \, dr \, d\theta$

$$\iiint_E f(x, y, z) \, dV = \iiint_E f(r \cos \theta, r \sin \theta, z) \, r \, dz \, dr \, d\theta$$

↑

11. Triple integrals in Spherical Coordinates: $\begin{cases} x = (\rho \sin \phi) \cos \theta \\ y = (\rho \sin \phi) \sin \theta \\ z = \rho \cos \phi \end{cases}, \quad dV = \rho^2 \sin \phi \, d\rho \, d\phi \, d\theta$

$$\iiint_E f(x, y, z) \, dV = \iiint_E f(\rho \sin \phi \cos \theta, \rho \sin \phi \sin \theta, \rho \cos \phi) \rho^2 \sin \phi \, d\rho \, d\phi \, d\theta$$

↑

12. Vector fields on \mathbb{R}^2 and \mathbb{R}^3 : $\vec{F}(x, y) = \langle P(x, y), Q(x, y) \rangle$ and $\vec{F}(x, y, z) = \langle P(x, y), Q(x, y), R(x, y) \rangle$;
 \vec{F} is a conservative vector field if $\vec{F} = \nabla f$, for some real-valued function f .