Optics: Reflection, Refraction, and Absorption

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Department of Aesthetic and Laser Technology
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Course & Laboratory Context

Department of Aesthetic and Laser Technology
Instructor: Assist Lect. ISMAEL A. GHNEI
Laboratory Module: Practical Medical Optics and Laser Physics
Academic Focus: Understanding light-matter interaction, ray tracing, beam alignment, and tissue optics in aesthetic practice.

Practical Laboratory Framework

Historical Foundations

Newton and Huygens principles of light propagation and corpuscular-wave theories.

Wavefronts & Rays

Straight line propagation, shadow formation, and beam divergence mechanics.

Law of Reflection

Specular and diffuse reflection on skin surfaces and laser delivery optics.

Snell's Law Dynamics

Refractive indices, angle changes across media, and dispersion through prisms.

Internal Reflection

Critical angle conditions and optical fiber transmission in laser handpieces.

Tissue Absorption

Beer-Lambert attenuation, chromophore targeting, and laboratory safety rules.



Evolution of Optical Science

Optical study began over 350 years ago with Newton and Huygens, establishing straight-line propagation, reflection equality, and medium refraction. In 1960, Theodore Maiman demonstrated the first working ruby laser using optical reflection resonators.

تطور علم البصريات عبر نيوتن وهايغنز وصولا
، معتمدا1960إلى اختراع أول ليزر ياقوتي عام
على المرايا العاكسة لتحفيز الانبعاث.

Core Empirical Facts of Light

1. Straight Lines

Light propagates along straight lines in homogeneous media. The primary physical evidence is the geometric formation of sharp shadows.

الانتشار بخطوط مستقيمة ودليلها تكون الظلال.

2. Reflection Equality

Rays reflecting off planar surfaces maintain equal incident and reflected angles, preserving exact 1:1 image scales in flat mirrors.

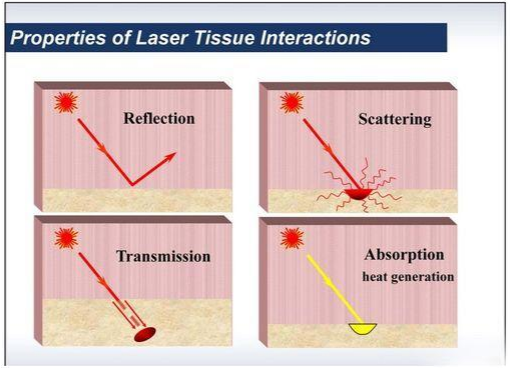
تساوي زوايا السقوط والانعكاس تماما في المرايا المستوية.

3. Boundary Deflection

Crossing media interfaces deflects rays (refraction). At narrow apertures, slit projection broadens beyond geometric limits due to diffraction.

انكسار الضوء عبر الأوساط وحيوده عند الحواف الضيقة.

Light-Matter Pathways



When a clinical laser strikes biological tissue, four primary physical phenomena occur simultaneously:

1. Reflection at stratum corneum boundary
2. Scattering across dermal collagen fibers
3. Transmission through non-absorbing depths
4. Absorption converting photon energy into heat

المسارات الأربعة لشعاع الليزر عند ملامسة الجلد: الانعكاس السطحي، التشتت الجلدي، النفاذ العميق، والامتصاص الانتقائي المحول للحرارة.

01

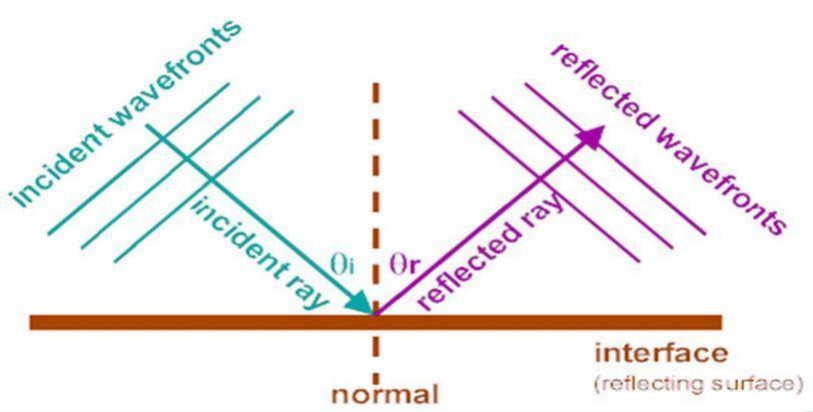
Law of Reflection

Investigating specular surface mechanics, wavefront geometry, and mirror alignment in laser delivery arms.

Geometric Reflection

The law of reflection states that the incident ray, reflected ray, and surface normal all lie within the same plane: $r\vartheta = i\vartheta$

Incident wavefronts encounter the reflecting interface, causing secondary wavelets to reconstruct the reflected wavefront at an identical exit angle.



قانون الانعكاس: زاوية السقوط تساوي زاوية الانعكاس بالنسبة للعمود المقام على السطح العاكس.

Specular vs Diffuse Reflection

Specular Reflection (انعكاس منتظم):
Occurs on optically smooth surfaces where surface micro-roughness is smaller than laser wavelength. Parallel incoming rays reflect as parallel outgoing rays. Utilized in laser articulated delivery arms, cavity mirrors, and beam splitters.

Diffuse Reflection (انعكاس غير منتظم/ مبعثر):
Occurs on microscopically rough surfaces such as human skin. Incoming rays reflect at random multi-directional angles according to Lambertian scattering. Causes clinical laser radiation hazards across the entire treatment suite.

Calculation 1: Mirror Reflection

Problem: In an articulated arm delivery system, an Alexandrite laser beam strikes a dielectric steering mirror at an incident angle of $\theta_i = 35°$relative to the normal

.1.Find reflected angle :$\theta_r = \theta_i = 35°$

2 .Find total beam deflection :$\delta = 180° - 2\theta_i = 180° - 70° = 110°$

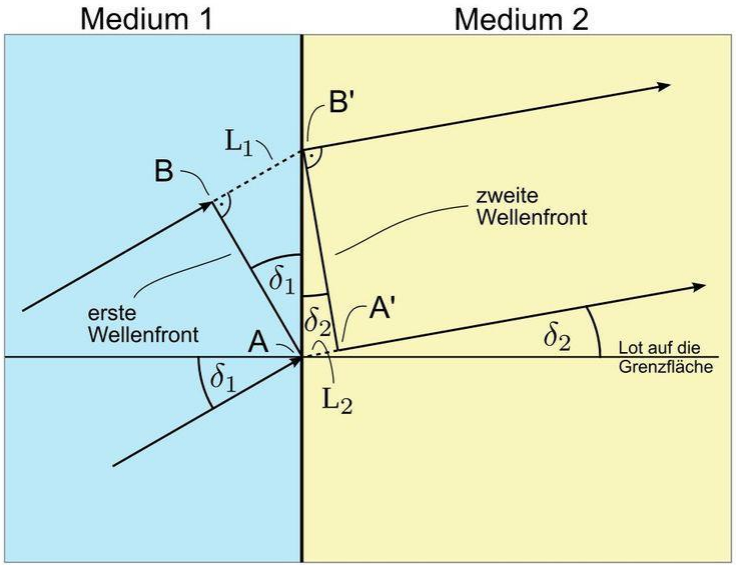
مسألة 1: زاوية

الانعكاس تساوي زاوية السقوط (35 درجة)، وزاوية انحراف الشعاع الكلية هي 110 درجات.

02

Refraction Mechanics

Analyzing phase velocity deceleration, refractive indices, and path deviation using Snell's optical formulation.



Snell's Law Formulation

When light enters an optically denser medium, its propagation velocity slows from v_1 to v_2 ,bending the wavefront toward the normal :

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

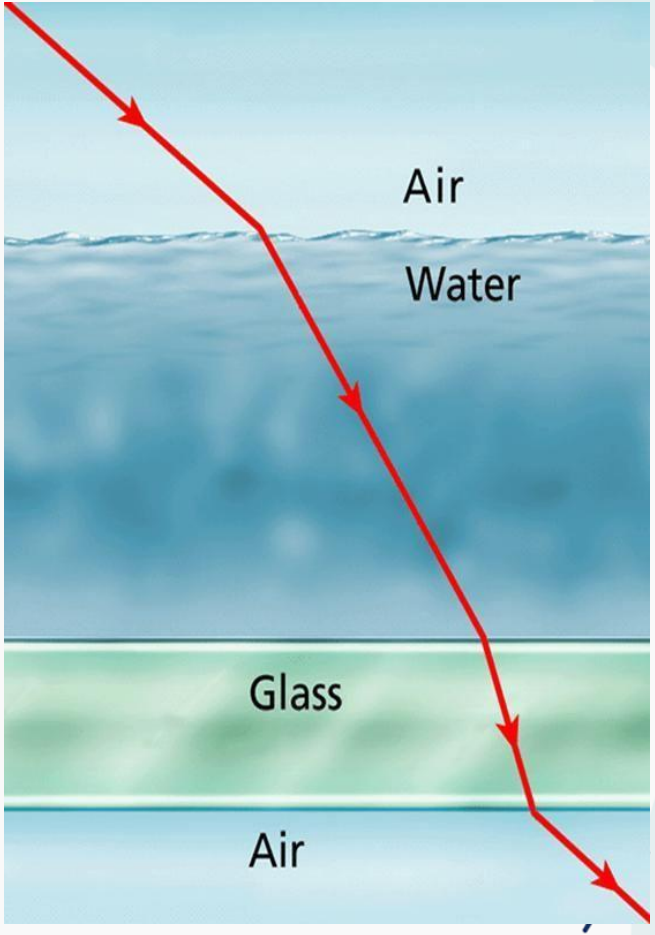
Where refractive index is $n = c/v$.

يصف العلاقة بين :قانون سنيل للانكسار
زوايا السقوط والانكسار ومعاملات
الانكسار للأوساط الشفافة.

Multi-Layer Refraction

As demonstrated in the lecture diagram, light travelling through Air →Water →Glass bends consecutively: - Air to Water: Bends toward normal ($n_{water} > n_{air}$ - (Water to Glass: Bends further toward normal($n_{glass} > n_{water}$) - Glass to Air: Bends away from normal back to parallel

تغير اتجاه مسار الضوء عند انتقاله بين الهواء، الماء، والزجاج تبعا لاختلاف الكثافة البصرية.



Clinical Refractive Indices

Air & Water

Air has $n \approx 1.000$,while water has $n \approx 1.333$ .Since soft tissue is 70% water, cellular baseline index is close to water.

معامل انكسار الهواء1.00 والماء1.33.

Skin Tissue

Stratum corneum has $n \approx 1.50$,while living epidermis and dermis average $n \approx 1.37 - 1.42$, causing optical mismatch at the interface.

معامل انكسار طبقات الجلد يتراوح بين1.37 و1.50.

Coupling Gel

Optical gels ($n \approx 1.35$) and sapphire handpiece tips ($n \approx 1.76$) eliminate trapped air gaps to maximize light coupling.

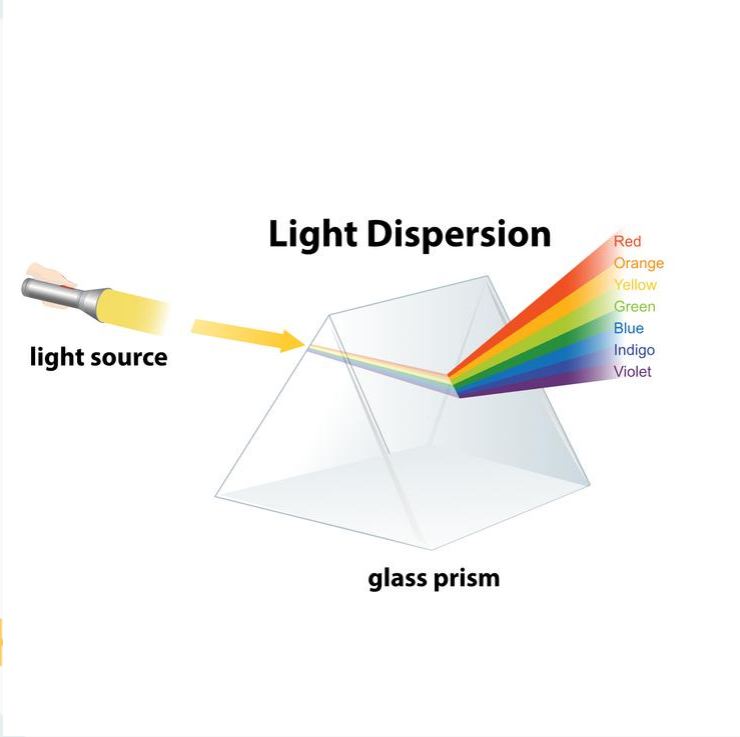
الجل البصري وحجر الياقوت يقللان الفقد الانعكاسي السطحي.

Calculation 2: Skin Refraction

Problem: A diode laser beam (810 nm) exits air($n_1 = 1.00$ (and enters the epidermis ($n_2 = 1.40$ (at an incident angle $\theta_1 = 40°$.

1. Formula: $\sin(\theta_2) = \frac{n_1}{n_2}\sin(\theta_1)$
2. Calculation: $\sin(\theta_2) = \frac{1.00}{1.40}\sin(40°) = \frac{0.6428}{1.40} \approx 0.4591$
3. Refracted Angle: $\theta_2 = \arcsin(0.4591) \approx 27.33°$

مسألة 2: ينكسر شعاع الليزر داخل البشرة بزاوية 27.33 درجة مقتربا من العمود المقام.



Prism Dispersion & Color

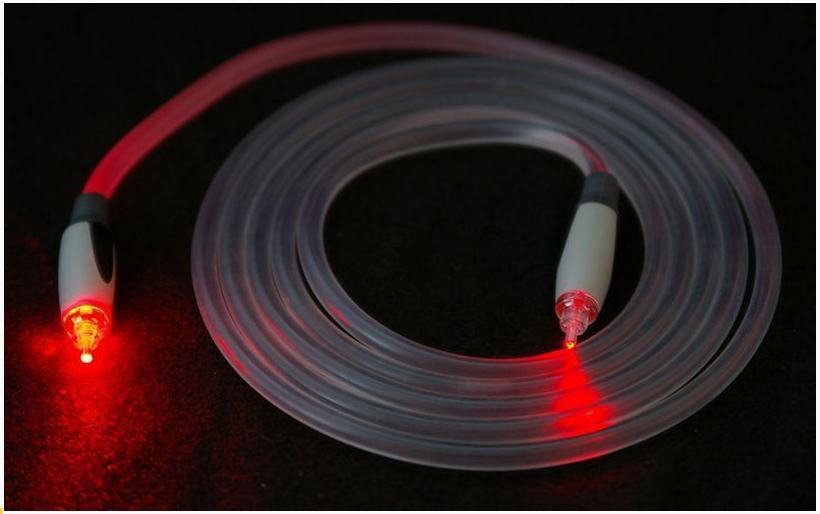
White light entering a prism separates into spectral bands because the refractive index λ varies inversely with wavelength (dispersion). Shorter wavelengths (violet, 400 nm) refract more sharply than longer wavelengths (red, 700 nm). In contrast, medical lasers emit single, monochromatic wavelengths.

تشتت الضوء الأبيض عبر المنشور بسبب اختلاف معامل الانكسار تبعا لطول الموجة، بينما يمتاز الليزر بأنه أحادي اللون تماما.

03

Total Internal Reflection

Waveguide confinement, critical angle criteria, and fiber optic delivery systems in modern aesthetic lasers.



Optical Fiber Delivery

When light travels from a higher index medium (n_1) toward a lower index medium(n_2)at an incident angle exceeding the critical angle θ_c %100 ,of the light is reflected internally :

$$\sin(\theta_c) = \frac{n_2}{n_1}$$

This principle enables flexible silica optical fibers to transmit high-energy laser pulses directly to the handpiece without transmission loss.

الانعكاس الكلي الداخلي يسمح بنقل طاقة الليزر عبر الألياف الضوئية دون فقدان للطاقة عند تجاوز الزاوية الحرجة.

Calculation 3: Critical Angle

Problem: An aesthetic laser optical fiber features a silica core with $n_1 = 1.48$and a fluoropolymer cladding with $n_2 = 1.40$

.1 .Formula: $\theta_c = \arcsin\left(\frac{n_2}{n_1}\right)$

2. .Ratio: $\frac{1.40}{1.48} \approx 0.9459$

3. .Critical Angle: $\theta_c = \arcsin(0.9459) \approx 71.07°$Rays hitting the boundary at angles $\geq 71.07°$experience total internal reflection.

مسألة 3: الزاوية الحرجة لليف البصري هي 71.07 درجة. أي زاوية سقوط أكبر منها تضمن انعكاسا كليا بنسبة 100%.

04

Tissue Absorption

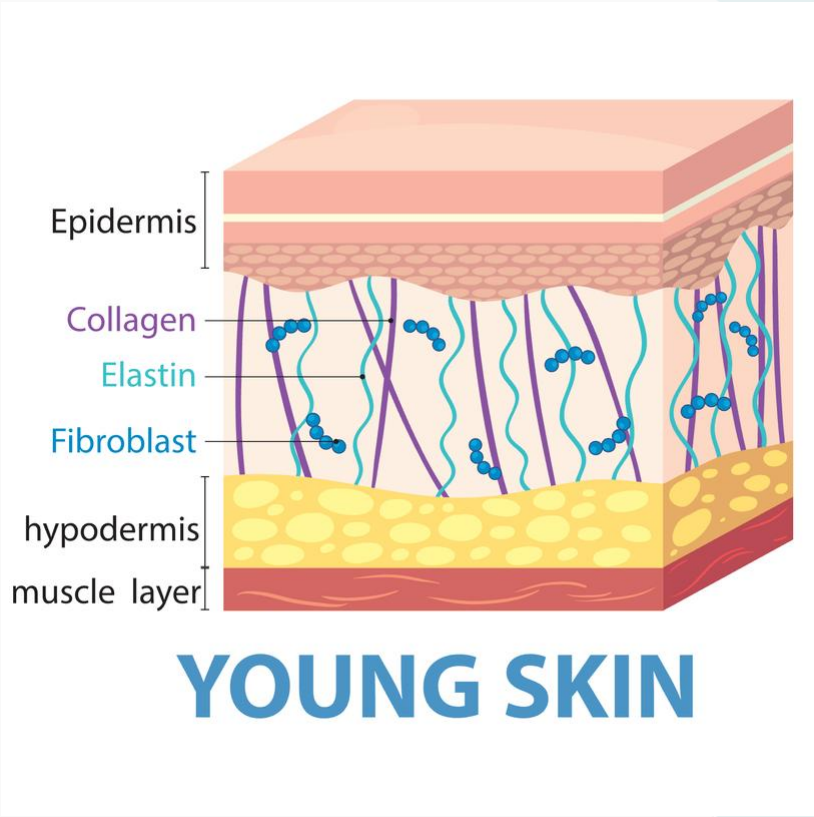
Beer-Lambert exponential attenuation, primary chromophores, and selective photothermolysis in laser aesthetics.

Target Skin Chromophores

Laser absorption in dermatology requires selective uptake by endogenous chromophores:

- Melanin: Absorbs 1100 -400 nm (hair removal, pigmented lesions)
- Hemoglobin: Absorbs 577 &542 nm (vascular lesions, telangiectasia)
- Water: Absorbs > 1400 nm ,peaking at 2940 nm & 10600 nm (fractional resurfacing)

امتصاص طاقة الليزر يتم عبر الكروموفورات (المستهدفة، الميلانين في التصبغات والشعر، الهيموغلوبين في الأوعية، والماء في تقشير الجلد).



Calculation 4: Beer-Lambert Law

Problem: A Nd:YAG laser beam ($I_0 = 100$ J/cm^2)penetrates dermal tissue with an absorption coefficient $\mu_a = 0.4$ mm^{-1} .Calculate intensity at depth $z = 3$ mm .1 .

1. Formula :$I(z) = I_0 \cdot e^{-\mu_a \cdot z}$

2 .Exponent :$-\mu_a \cdot z = -(0.4 \cdot 3) = -1.2.$

3. Intensity :$I(3) = 100 \cdot e^{-1.2} = 100 \cdot 0.3012 \approx 30.12$ J/cm^2

مسألة 4: يتلاشى إشعاع الليزر أسيّا داخل الأنسجة؛ تنخفض الشدة من 100 إلى 30.12 جول/سم² عند عمق 3 ملم.



Aesthetic Laser Workstations

Modern medical aesthetic systems integrate Alexandrite (755 nm) and Nd:YAG (1064 nm) sources. Internal steering mirrors reflect pulses through focus lenses into armored fiber bundles, delivering controlled optical fluences to targeted dermal structures.

منظومة الليزر الطبية تجمع بين الانعكاس الداخلي، التركيز العدسي، والتوصيل الليفي لمعالجة الشعر والأوعية بدقة عالية.

Practical Lab Protocol

01 Optical Alignment & Setup

Mount diode laser on the optical bench. Level target mirrors and zero the goniometer. ضبط ومحاذاة منضدة الليزر.

02 Reflection Angle Measurement

Direct beam at planar mirror across 20 to 70 degrees; verify theta_i = theta_r. التحقق من تطابق زوايا الانعكاس.

03 Refraction Index Determination

Pass beam through acrylic block and water cell; measure displacement to solve for n. حساب معامل الانكسار عبر قانون سنيل.

04 Attenuation & Absorption Curve

Interpose phantom skin layers; measure power output with photodetector to verify Beer-Lambert law. قياس التوهين والامتصاص.

Laser Safety & Clinical Standards

Optical Protection Standards (ANSI Z :(136
1. .Mandatory wavelength-specific goggles matching system wavelength
2.Optical Density rating :OD ≥ 5at active emission bands
3.Non-reflective matte instruments to eliminate specular reflection stray beams
4 .Controlled Nominal Hazard Zone (NHZ) access doors

معايير السلامة الليزرية في المختبر والعيادة:
1. ارتداء نظارات حماية مطابقة لطول الموجة المنبعثة
2. كثافة بصرية كافية لمنع أضرار الشبكية
3. تجنب الأدوات اللامعة لمنع ارتداد الحزم الليزرية العرضية
4. تحديد منطقة الخطر البصري والالتزام التام بإشارات التحذير

Practical Lab Summary & Assessment

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