MOLEKÜLER SPEKTROSKOPİNİN
TEMEL PRENSİPLERİ VE UYGULAMALARI

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Moleküler Spektroskopinin Temel Prensipleri ve Uygulamaları

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ÖNSÖZ

Bilimsel bilginin derinleştiği her dönemde, doğa olaylarının mikroskobik düzeyde anlaşılmasında en güçlü yöntemlerden biri spektroskopidir. Maddenin elektromanyetik radyasyon ile olan etkileşimini inceleyen bu yöntemler, sadece temel moleküler yapıların değil, aynı zamanda canlı sistemlerin, çevresel kirleticilerin ve gelişmiş malzemelerin analizinde de vazgeçilmez hale gelmiştir. Spektroskopinin bu çok yönlü uygulama alanı, moleküler düzeyde nicel ve nitel bilgi elde edilmesini mümkün kılarak fizik, kimya, biyoloji, malzeme bilimi ve mühendislik gibi farklı disiplinler arasında güçlü bir köprü kurmaktadır. Bu kitap, spektroskopik tekniklerin temel prensiplerinden başlayarak uygulamalı yönlerine uzanan kapsamlı bir akademik kaynak sunmayı hedeflemektedir. Moleküler spektroskopinin kuramsal temelleri, elektromanyetik spektrumun bölgesel özellikleri, ışığın maddeyle etkileşimi ve kuantum mekaniği tabanlı geçiş süreçleri ayrıntılı olarak ele alınmıştır. Ayrıca, tıp, eczacılık, biyomedikal, çevre ve malzeme bilimleri gibi güncel ve disiplinler arası uygulama alanlarına da özel bölümler ayrılmıştır. Bu bağlamda kitap, sadece temel kavramların öğretimiyle sınırlı kalmayıp aynı zamanda güncel araştırma alanlarına ışık tutan örnekleri ve tartışmalarıyla da akademik çalışmalara katkı sunmayı amaçlamaktadır.

Kitabın oluşturulmasında katkıda bulunan tüm yazarlar, kendi uzmanlık alanlarında birikimlerini paylaşarak hem disipliner derinliği hem de uygulama çeşitliliğini mümkün kılmışlardır. Her bir bölüm, ilgili alandaki gelişmeler dikkate alınarak titizlikle hazırlanmış ve bilimsel bütünlük çerçevesinde değerlendirilmiştir. Okuyucuların bu eserden teorik bilgi yanında uygulama vizyonu da edinmesi önemli amaçlardandır.

Bu kitabın, başta fen ve mühendislik fakülteleri ile sağlık bilimleri alanlarında öğrenim gören lisans ve lisansüstü öğrenciler olmak üzere, araştırmacı akademisyenler, AR-GE uzmanları ve disiplinler arası çalışan bilim insanları tarafından yararlanılabilecek nitelikli bir başvuru kaynağı olarak değerlendirilmesi hedeflenmiştir.

Kitabın hazırlanmasında katkı sunan tüm yazarlarımıza, hakemlik süreçlerinde özveriyle değerlendirme yapan akademisyenlere ve yayıma hazırlık aşamasında emeği geçen tüm paydaşlara teşekkür ederim.

Saygılarımla,

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BÖLÜM 1

MOLEKÜLER SPEKTROSKOPİYE VE SENSÖR BİLİMİNE GİRİŞ

Bahri GÜR[1]

"Moleküler yapıyı anlamanın yolu, elektromanyetik ışığın izini okumaktan geçer."

GİRİŞ

Spektroskopi, elektromanyetik radyasyonun madde ile etkileşimin incelenmesidir. Işığın dalga boyuna veya frekansına bağlı olarak madde tarafından soğurulma (absorpsiyon), yayılma (emisyon) veya saçılma dinamiklerini analiz eder. Spektroskopi, atomik, moleküler ve daha büyük ölçekli maddelerin elektromanyetik radyasyonla etkileşimlerini inceleyen disiplinler arası bir bilim alanıdır.

Moleküler spektroskopi ise, spektroskopinin molekülleri inceleyen alt dalıdır. Sadece atomik yapıları değil, atomların birbirine bağlanarak oluşturduğu moleküler yapıların elektromanyetik radyasyon (EMR) ile etkileşimini inceleyen bilim dalıdır. Elektromanyetik ışınım, yayılma doğrultusuna ve birbirlerine dik konumlanmış elektrik ve manyetik alan vektörlerinin, aynı fazda ilerleyen sinüzoidal salınımlarıyla karakterize edilir (Griffiths, 2023). Moleküler spektroskopi tekniklerinde özellikle moleküllerin enerji düzeyleri arasındaki geçişlerin absorpsiyon veya emisyon yoluyla incelenmesi hedeflenmektedir. Elde edilen veri genellikle spektrum adı verilen, ışınım şiddetinin dalga boyu, frekans veya

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- **Molecular Spectroscopy** (https://www.ossila.com/pages/history-of-spectroscopy**, Erişim Tarihi:15.12.2025).** ***Ossila Online Resources.*** – Ossila firmasının eğitim amaçlı çevrimiçi kaynaklarından spektroskopi ile ilgili sayfalar, spektroskopinin tarihçesi ve temel tanımlarına güncel bir bakış sunmaktadır. Ayrıca spektroskopi türlerine dair kısa özetler ve uygulama notları içerir (örneğin floresans ve "What is Spectroscopy?" alt bölümleri).
- **NIST Chemistry WebBook –** ***Infrared and UV-Vis Spectra Database.*** – Ulusal Standartlar ve Teknoloji Enstitüsü (NIST) tarafından sunulan çevrimiçi spektrum kütüphanesi. Birçok molekülün referans IR, kütle ve UV-Vis spektrumlarını içerir. Uygulamalı spektroskopide, deneysel spektrumların yorumlanması için güvenilir bir karşılaştırma kaynağı olarak kullanılabilir.
- **Banwell, C. N., & McCash, E. M. (1994).** ***Fundamentals of Molecular Spectroscopy*** **(4. Baskı). McGraw-Hill. –** Her ne kadar 10 yıldan eski olsa da, moleküler spektroskopinin temellerini öğrenmek isteyenler için sade ve öğretici bir kaynaktır. Döneminin terminolojisi ve örnekleriyle, bugünkü temel bilgilerin anlaşılmasına yardımcı olur.

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BÖLÜM 2

SPEKTROSKOPİK TEKNİKLERİN TEMELLERİ

Tuğba BAYRAKTUTAN [1]

GİRİŞ

Spektroskopik teknikler, elektromanyetik radyasyon ile madde arasındaki etkileşime dayanır. Bir numunenin moleküler veya atomik yapısı, içeriği ve fiziksel özellikleri hakkında kapsamlı bilgiler elde etmek için çeşitli dalga boylarında ışığın emilimini, emisyonunu veya saçılımını içerir.

Temel ilkeler şunlardır:

» Elektromanyetik radyasyon bir örnekten geçerken veya onunla etkileşime girdiğinde, belirli dalga boyları emilir; bu da moleküler veya atomik enerji durumları arasındaki enerji geçişlerine karşılık gelir.

» Çeşitli spektroskopi türleri, elektronik değişiklikler (UV-Gör bölge absorpsiyon spektroskopisi), titreşim geçişleri (IR ve Raman spektroskopisi) veya nükleer spin geçişleri (NMR spektroskopisi) dahil olmak üzere farklı enerji geçişlerine odaklanır.

» Ölçülen spektrum, bileşiklerin tanımlanmasını ve kantitatif analizini kolaylaştıran bir moleküler parmak izi görevi görür.

» Enstrümantasyon, bir ışık kaynağı, bir numune tutucu, dalga boyu ayırma için bir dağıtıcı eleman veya filtre ve yoğunluk değişikliklerini ölçmek için bir dedektörden oluşur.

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BÖLÜM 3

SPEKTROSKOPİK CİHAZLARIN YAPISI VE ÇALIŞMA PRENSİPLERİ

İlker AKIN [1]

GİRİŞ

Spektroskopik cihazlar, bir maddeyi ışık veya diğer elektromanyetik dalgalar kullanarak analiz etmek için kullanılan araçlardır. Bu cihazlar, genellikle ışığın madde ile etkileşimi sonucu elde edilen bilgiyi ölçerek bileşenlerin kimyasal ve fiziksel özellikleri hakkında bilgi verir. Genellikle ışık madde etkileşimi absorpsiyon, emisyon, saçılma, kırınım ve uyarılma şeklinde gerçekleşir. Bu etkileşimler-de Bölüm 2'de belirtilen spektroskopik tekniklerin temellerini oluşturmaktadır.

1. SPEKTROMETRE BİLEŞENLERİ

Spektroskopik cihazlar, temelde aşağıdaki ana bileşenlerden oluşur:

» Işık Kaynağı (Veya Radyasyon Kaynağı): Cihaz, analiz yapılacak maddeyi uyaracak bir ışık kaynağına ihtiyaç duyar. Bu kaynak genellikle geniş spektrumlu ışık yayar (örneğin, beyaz ışık, lazer veya X-ışınları). Işık kaynağı, maddeden geçerken bazı dalga boylarını soğurabilir, yansıtabilir veya saçabilir. Işık kaynağının tipi, spektroskopik analiz türüne göre değişir.

» Monokromatör (Fotonları Ayıran Sistem): Spektroskoplarda genellikle bir monokromatör bulunur. Monokromatör, ışığı farklı dalga boylarına ayırır. Bu ayırma işlemi, ışığın spesifik dalga boylarına odaklanarak hangi bölge-

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BÖLÜM 4

SPEKTROSKOPİK VERİLERİN ANALİZİ VE YORUMLANMASI

Serkan DEMİREL[1]
Adem KOÇYİĞİT[2]

1. SPEKTROSKOPİK VERİLERİN DOĞASI VE TEMEL İSTATİSTİKSEL KAVRAMLAR

Spektroskopik yöntemler, bir maddenin yapısal, elektronik ve kimyasal özelliklerini elektromanyetik ışınım ile etkileşimini temel alarak ortaya koyan güçlü analitik süreçler olarak tanımlanabilir. Bu yöntemlerden elde edilen spektral veriler, tipik olarak dalga sayısı ($\tilde{\nu}$), ışık şiddeti (I) veya dalga boyu (λ) gibi bir bağımsız değişken ile emisyon, soğurma, geçirme veya saçılma gibi bir bağımlı değişken arasındaki fonksiyonel ilişkiye göre elde edilir. Spektroskopik ölçümler, gerek uygulamalı araştırmalarda, özellikle malzeme bilimi, kimya, farmasötik analiz, ilaç-hücre etkileşim analizleri (Baloglu et al., 2025), biyomedikal görüntüleme ve çevre bilimi alanlarında gerekse temel bilim alanlarında büyük öneme sahiptir (Skoog et al., 2014). Spektroskopik verilerin doğası incelediğinde, temel istatistiksel kavramların önemli rolü oynadığı ve etkili analizin ancak bu şekilde gerçekleştirilebileceği söylenebilir. İstatistiksel yöntemlerin yanlış uygulanması veya yanlış değerlendirilmesi sonucunda spektroskopik verilerin analizindeki güvenilirlik sarsılır. Ayrıca, yeni karmaşık enstrümantasyon yöntemlerinin ortaya çıkmasıyla, spektroskopi üzerine çalışan bilim insanlarının istatistiksel de-

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BÖLÜM 5

SPEKTRAL YAPI VE MOLEKÜLER YAPI İLİŞKİSİ

Faysal SELİMOĞLU [1]

GİRİŞ

Bir molekülün elde edilen spektrumu ister IR, Raman, UV-görünür, X-ışını kırınımı, NMR ya da kütle spektrometrisi yoluyla kaydedilmiş olsun temel olarak bağ türleri, molekülün simetrisi, elektron yoğunluğunun dağılımı ve çekirdek çevresindeki lokal kimyasal ortam tarafından belirlenir. Bu parametreler, her molekül için benzersiz ve tekrarlanabilir bir "spektral parmak izi" oluşturur (Nakamoto, 2008, Banerjee et al., 2020; Li & Wang, 2021). Titreşim spektroskopisi yöntemleri olan IR ve Raman, moleküldeki bağların esneme ve bükülme hareketlerine duyarlıdır. IR spektrumları özellikle dipol moment değişikliklerine, Raman spektrumları ise polarize edilebilirlikteki değişimlere tepki verir. Bu nedenle karbonil, hidroksil veya amin gibi fonksiyonel gruplar, karakteristik bantlarıyla kolayca tanımlanabilir (Nakamoto, 2008; Pavia, Lampman, Kriz, & Vyvyan, 2015 Ramanathan et al., 2022; Smith & Sharma, 2021).

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6.2 Spektral bantların (piklerin) yorumu

Pratik kurallar. Çokluk, n + 1 ve Pascal yoğunluklarına uyar; ancak kimyasal eşdeğerlik ve uzun menzil J'ler desenleri bozabilir. Vinylic bağlarda $^3J\_trans > {}^3J\_cis$, aromatikte $^3J\_ortho > {}^3J\_meta$, aldehitin vicinal ^3J değeri genellikle küçüktür. Anizotropi (C=O, C≡C, aromatik) yerel alanı değiştirir; aromatik dışında deshielding beklenirken, alkin protonunda beklenenin tersine yukarı saha gözlenir. Karışımlarda integrasyon için yeterli dinlenme gecesi ($\geq 5 \times \max T_1$) kullanılmalı; paramanyetik izler çizgileri genişletir. Dinamik süreçler (prototropi, konformasyon) orta hızda koalesans verir; VT-NMR ve EXSY ile enerji bariyeri çıkarılabilir (Claridge, 2016; Keeler, 2010; Levitt, 2008; denetim: 2025-10-05).

6.2.1 İzotop etkileri ve spektral kaymalar

H→D değişimi O–H / N–H sinyallerini D_2O ile ortadan kaldırır; ayrıca ^1H kimyasal kaymalarında ikincil izotop kaymaları görülebilir. ^{13}C doğal bolluk nedeniyle ^1H piklerinde ^{13}C uydu çiftleri (J_CH ~ 125–160 Hz) belirir; ^{13}C-zenginleştirme HSQC/HMBC hassasiyetini ciddi artırır. ^{15}N düşük γ ve bolluğa rağmen ^1H–^{15}N HSQC/HMBC ile amin/amit tanısında faydalıdır. Kuadrupolar çekirdekler (^{14}N, ^{11}B) hızlı gevşeyip komşu protonları genişletir; ^{15}N kullanımı veya pH/çözücü seçimi ile hatlar daraltılabilir. Çözücü izotopları ($CDCl_3$, DMSO-d_6, CD_3OD) lock/shim kararlılığı sağlarken, özgül etkileşimler δ'yı oynatır; raporda çözücü daima belirtilmelidir (Keeler, 2010; Claridge, 2016; Levitt, 2008; Pavia et al., 2015; denetim: 2025-10-05).

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BÖLÜM 6

MALZEME BİLİMİNDE SPEKTROSKOPİ

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GİRİŞ

Malzeme bilimi, farklı endüstriyel ve teknolojik alanlarda kullanılan yeni nesil malzemelerin tasarımı, geliştirilmesi ve karakterizasyonunu amaçlayan disiplinler arası bir araştırma alanıdır. Bu süreçte, malzemelerin atomik ve moleküler düzeyde yapısal, elektronik ve yüzey özelliklerinin doğru biçimde anlaşılması büyük önem taşımaktadır. Spektroskopi, ışığın madde ile etkileşimine dayalı güçlü bir analitik yöntem olarak, malzeme biliminin temel araştırma araçlarından biri haline gelmiştir. Çeşitli spektroskopik teknikler, malzemelerin kimyasal bileşimini, kristal yapısını, fonksiyonel gruplarını ve elektronik özelliklerini ortaya koyarak hem temel bilimsel çalışmalara hem de endüstriyel uygulamalara değerli katkılar sunmaktadır.

Kızılötesi (IR) ve Raman spektroskopisi, polimerler, seramikler ve kompozitlerde bağ titreşimlerini ve fonksiyonel grupları tanımlamak için yaygın olarak kullanılmaktadır. UV-görünür spektroskopisi, yarı iletkenlerde ve nanomalzemelerde bant aralığının belirlenmesine olanak tanıyarak optoelektronik cihazların geliştirilmesinde kritik bir rol üstlenmektedir. X-ışını fotoelektron spektroskopisi (XPS), malzeme yüzeyindeki elementlerin kimyasal durumlarını ve bağ enerjilerini ortaya koyarken; enerji dağılımlı X-ışını spektroskopisi (EDS/EDX), özellikle metal alaşımlar ve kompozitlerde elementel bileşim hakkında ayrıntılı bilgiler sağlamaktadır.

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etkileşimleri destekleyen ve inovatif çözümler üretilmesine katkı sunan stratejik bir araç olarak değerlendirilmektedir.

Gelecekte, daha hassas, çok işlevli ve entegre spektroskopik sistemlerin geliştirilmesiyle birlikte, malzeme biliminin sınırlarının daha da genişlemesi ve daha karmaşık yapıların anlaşılmasında yeni olanakların doğması beklenmektedir. Bu nedenle, spektroskopinin teorik altyapısının yanı sıra uygulamalı yönlerinin de kapsamlı bir biçimde anlaşılması, malzeme araştırmalarında derinlemesine analizler yapılmasını sağlayacak ve bu alandaki bilimsel ilerlemeyi hızlandıracaktır.

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BÖLÜM 7

BİYOORGANİK MOLEKÜLLERDE YAPISAL ÖZELLİK–SPEKTRAL DAVRANIŞ İLİŞKİSİ

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GİRİŞ

Biyoorganik kimya, canlı sistemlerdeki kimyasal süreçleri organik kimya ilkeleriyle açıklamayı amaçlayan disiplinler arası bir bilim dalıdır. Bu alan, yalnızca moleküllerin kimyasal bileşimlerini değil, aynı zamanda yaşamın moleküler düzeyde nasıl işlediğini anlamayı hedefler. Biyoorganik moleküller, temel olarak karbon iskeletine sahip, oksijen, azot, fosfor ve kükürt gibi heteroatomlar içeren, biyolojik sistemlerde özgül işlevlere sahip organik bileşiklerdir (Poulter, 2009, van der Donk, 2023; Silverman & Holladay, 2023). Bu yapıların en ayırt edici özelliği, organik kimyanın kovalent bağlanma ilkelerini biyolojik düzenin seçiciliğiyle birleştirmeleridir.

Biyoorganik kimya, organik kimya ile biyokimya arasında köprü kuran bir alandır. Organik sentez yöntemleriyle elde edilen moleküllerin biyolojik süreçlerde nasıl etkileştiğini araştırır. Bu kapsamda enzimler, koenzimler, nükleotitler, peptitler, karbonhidratlar ve lipitler gibi temel biyomoleküller incelenir (Khan & Malhotra, 2018). Her biri, canlı organizmalarda enerji dönüşümü, sinyal iletimi, kataliz ve genetik bilgi aktarımı gibi yaşamsal süreçlerde görev alır.

Biyoorganik moleküllerin yapısal özellikleri, onların işlevsel rollerinin belirleyicisidir. Bir molekülün fonksiyonu, çoğu zaman üç boyutlu konformasyonu, kiral merkezlerinin uzaysal düzeni ve fonksiyonel gruplarının etkileşim kapasi-

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Tablo 2. Makromoleküller İçin Temel Spektroskopik Yöntemler

Yöntem	Ölçtüğü Özellik	Uygulama Alanı	Temel Bilgi, Kullanım ve Kaynak
IR	Dipol moment değişimi	Proteinler, DNA/RNA, polisakkaritler, lipitler	Amide bantları sekonder yapı; C–O–C ve O–H titreşimleri bağ tipi ve hidrojen ağı verir (Nakamoto et al., 2008).
Raman	Polarize edilebilirlik değişimi	Proteinler, nükleik asitler, lipitler	Disülfit ve aromatik bantlar zincir düzenini, fosfodiester bantları DNA yapısını gösterir (Nakamoto et al., 2008).
UV-Vis	Elektronik geçişler	Proteinler, DNA/RNA	280 nm proteini, 260 nm DNA'yı tanımlar; hipokromik etki heliks kararlılığını yansıtır (Lakowicz et al., 2006).
Floresans	Emisyon kayması, ömür	Proteinler, lipitler	Triptofan floresansı çevresel polariteyi; Laurdan probu membran fazını gösterir (Lakowicz et al., 2006).
CD	Kiral soğurma farkı	Proteinler, DNA	Far-UV heliks oranı, near-UV yan zincir yönelimi belirler (Lakowicz et al., 2006).
NMR	Kimyasal kayma, spin etkileşimi	Proteinler, nükleik asitler	2D/3D deneyler atomik yakınlık ve konformasyon verir (Claridge et al., 2016).
EPR	Elektron spin etkileşimi	Metaloproteinler	Oksidasyon durumu ve redoks merkezleri izlenir (Gross et al., 2017).
MS / ESI / MALDI	Kütle/yük oranı	Proteinler, nükleik asitler	Dizileme ve modifikasyonlar belirlenir (Aebersold et al., 2003).
XRD / XPS / XAFS	Atom düzeni, oksidasyon	Protein kristalleri, lipit yüzeyleri	XRD geometriyi, XPS yüzey kimyasını, XAFS metal çevresini tanımlar (Cotton et al., 1999).
Zaman-Çözünür Teknikler	Enerji ve yapı değişimi	Proteinler, DNA	TR-IR ara türleri, floresans ömrü bağlanma kinetiğini gösterir (Lakowicz et al., 2006; Claridge et al., 2016).

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BÖLÜM 8

SPEKTROSKOPİNİN FARMASÖTİK VE BİYOMEDİKAL UYGULAMALARI

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GİRİŞ

Spektroskopi, madde ile elektromanyetik ışınım arasındaki etkileşimi inceleyen ve kimyasal, fiziksel ve biyolojik sistemlerin temel özelliklerini anlamamızı sağlayan en güçlü analitik yöntemlerden biridir. Farmasötik ve biyomedikal bilimlerde ise bu yöntem, moleküler yapıların aydınlatılması, ilaç etken maddelerinin tanımlanması, biyomoleküler etkileşimlerin belirlenmesi ve hastalıkların erken tanısı gibi kritik alanlarda vazgeçilmez bir araç haline gelmiştir (Nakamoto, 2008; Lakowicz, 2006).

Modern spektroskopik teknikler —örneğin UV–Vis, FTIR, Raman, NMR, floresans ve fotolüminesans (PL) spektroskopileri— farmasötik ürünlerin kalite kontrolünden hücresel düzeyde biyolojik süreçlerin analizine kadar geniş bir uygulama yelpazesi sunar. Bu yöntemler hem nitel hem nicel analizlerde yüksek doğruluk sağlar; örneğin UV–Vis spektroskopisi farmasötik formülasyonların absorpsiyon karakteristiklerini belirlerken, FTIR ve Raman spektroskopisi moleküler titreşimleri kullanarak bileşiklerin fonksiyonel gruplarını tanımlar. NMR spektroskopisi moleküler yapı tayininde altın standart olarak kabul edilirken, floresans ve PL teknikleri ilaç–biyomolekül etkileşimlerinin ve hücresel yanıtların incelenmesinde eşsiz bir hassasiyet sunar (Claridge, 2016).

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Bununla birlikte, standardizasyon, cihazlar arası aktarılabilirlik, veri kalitesi, örnek hazırlama tutarlılığı ve klinik validasyon gereksinimleri devam eden sınırları oluşturur. Regülasyon uyumu, izlenebilirlik, açıklanabilir yapay zekâ ve çok merkezli doğrulama çalışmaları, laboratuvardan sahaya geçişin olmazsa olmazlarıdır.

Genel resim açıktır: spektroskopi teknikleri, uygun örnekleme, sağlam ön işleme ve iyi kalibre edilmiş istatistik/ML modelleri ile birleştirildiğinde, farmasötik kalite güvencesi ve biyomedikal tanıda yüksek doğruluklu, hızlı ve maliyet etkin çözümler üretir. Yakın vadede taşınabilir sensörler, hiperspektral görüntüleme, gerçek zamanlı veri analitiği ve dijital ikiz tabanlı kontrol stratejileri yaygınlaşacaktır. Uzun vadede ise açıklanabilir yapay zekâ ile çok modlu spektroskopinin birleşimi, kişiselleştirilmiş tıp ve akıllı üretim ekosistemlerinin merkezinde yer alacaktır. Bu dönüşüm, daha güvenli ilaçlar, daha verimli süreçler ve daha erken, daha doğru klinik kararlar anlamına gelir.

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BÖLÜM 9

SENSÖR TEKNOLOJİSİ VE SPEKTROSKOPİK SENSÖRLER

Aybek YİĞİT[1]

GİRİŞ

Proses Analitik Teknolojisi (PAT) girişimi, ürün kalitesini güvence altına almak amacıyla ürün geliştirme ve üretim süreçlerinde nihai ürünün kritik kalite özelliklerini etkileyen tüm kritik proses parametrelerini izlemeyi ve kontrol etmeyi amaçlamaktadır (Claßen, et al. 2017). PAT'ın uygulanmasının temel nedenleri, yüksek kaliteli ürünler sağlamak için yeni teknolojilerinden yararlanmak, esnek üretime olanak sağlamak, arızaları ve enerji tüketimini azaltmak, proses anlayışını geliştirmek, operatör güvenliğini artırmak ve artan otomasyon ve gerçek zamanlı seri üretim yoluyla insan hatasını azaltmaktır (Rathore et al. 2010). Bu amaçla çalışmamızda, birçok alanda kullanılan sensörler ve spektrometrik sensörlerin tarihi, çeşitleri, özellikleri ve kullanım alanları hakkında detaylı bilgiler sunulmuştur.

AMAÇ VE KAPSAM

Spektroskopik sensörler, madde–ışık etkileşimine dayalı ölçüm prensipleri sayesinde yüksek duyarlılık ve seçicilik sunmalarından ötürü çevresel izleme, biyomedikal tanı ve endüstriyel süreç kontrolü vb. birçok alanda yaygın olarak tercih edilmektedir. Ancak, mevcut çalışmaların büyük çoğunluğu, laboratuvar ortamına bağımlı, maliyetli ve sınırlı taşınabilirliğe sahip sistemlere odaklanmaktadır.

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