NCERT Exemplar Solutions of Class 11 Biology – Chapter 20: Locomotion and Movement

LONG ANSWER TYPE QUESTIONS

1. Calcium ion concentration in the blood affects muscle contraction. Does it lead to tetany in certain cases? How will you correlate fluctuation in blood calcium with tetany?

Enhanced Solution:

Yes, calcium ion concentration fluctuations can lead to tetany.

Role of calcium in muscle contraction:

1. Normal muscle contraction mechanism:

Ca^{2+} ions bind to troponin C on thin filaments

Causes conformational change in tropomyosin

Exposes myosin binding sites on actin

Enables cross-bridge formation and muscle contraction

2. Calcium regulation:

Parathyroid hormone (PTH): Increases blood Ca^{2+} levels

Calcitonin: Decreases blood Ca^{2+} levels

Vitamin D: Enhances Ca^{2+} absorption

TETANY AND CALCIUM CORRELATION:

Hypocalcemic tetany (Low blood calcium):

Causes:

Parathyroid hormone deficiency: Hypoparathyroidism

Vitamin D deficiency: Poor calcium absorption

Magnesium deficiency: Required for PTH function

Alkalosis: Increases protein-bound calcium

Mechanism:

Increased nerve excitability: Low Ca^{2+} decreases threshold for nerve firing

Spontaneous depolarization: Nerves fire without stimulation

Continuous muscle stimulation: Results in sustained contractions

Clinical manifestations:

Carpopedal spasm: Contraction of hands and feet muscles

Laryngospasm: Vocal cord muscle spasm

Chvostek's sign: Facial muscle twitching when facial nerve tapped

Trousseau's sign: Hand spasm when blood pressure cuff inflated

Physiological explanation:

Normal Ca^{2+} levels: 8.5-10.5 mg/dL

Tetany threshold: Usually occurs when Ca^{2+} < 7 mg/dL

Membrane stability: Ca^{2+} stabilizes nerve membrane potential

Reduced calcium: Makes nerves hyperexcitable

Treatment:

Immediate: IV calcium gluconate

Long-term: Calcium supplements, Vitamin D, treat underlying cause

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2. An elderly woman slipped in the bathroom and had severe pain in her lower back. After X-ray examination doctors told her it is due to a slipped disc. What does that mean? How does it affect our health?

Enhanced Solution:

WHAT IS A SLIPPED DISC?

Definition: A slipped disc (herniated or prolapsed disc) is a condition where the **intervertebral disc is displaced from its original position** between vertebrae.

Anatomy of intervertebral disc:

Annulus fibrosus: Tough outer ring of fibrocartilage

Nucleus pulposus: Soft, jelly-like inner core

Function: Acts as shock absorber and allows spinal flexibility

Mechanism of injury:

Disc degeneration: Age-related wear and tear weakens annulus fibrosus

Sudden stress: Fall, lifting, or twisting motion

Rupture: Nucleus pulposus pushes through weakened annulus

Compression: Herniated material presses on spinal nerves or spinal cord

HEALTH EFFECTS:

Immediate effects:

Severe pain: Local back pain and radiating pain down legs (sciatica)

Muscle spasm: Protective muscle contractions around injury site

Limited mobility: Difficulty in bending, sitting, or walking

Neurological effects:

Nerve compression: Pressure on spinal nerves

Numbness and tingling: In legs, feet, or areas served by compressed nerves

Muscle weakness: In muscles innervated by affected nerves

Reflex changes: Diminished or absent reflexes

Long-term complications:

Chronic pain: Persistent lower back and leg pain

Permanent nerve damage: If left untreated

Cauda equina syndrome: Severe compression causing bowel/bladder dysfunction

Paralysis: In extreme cases with significant spinal cord compression

Functional limitations:

Activities of daily living: Difficulty in dressing, bathing, cooking

Occupational impact: May affect work performance and attendance

Social limitations: Reduced participation in recreational activities

Sleep disturbances: Pain interfering with sleep quality

Treatment options:

Conservative: Rest, physiotherapy, pain medications, epidural injections

Surgical: Discectomy, laminectomy in severe cases
Prevention strategies:
Proper lifting techniques: Bend knees, not back
Regular exercise: Strengthen core and back muscles
Weight management: Reduce stress on spine
Good posture: Maintain spinal alignment

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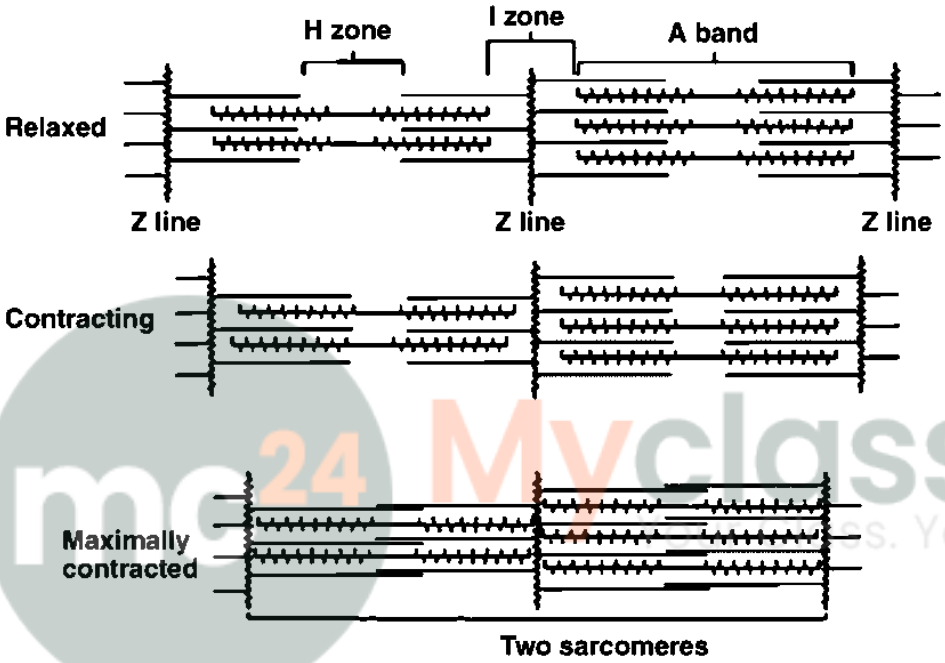
3. Explain sliding filament theory of muscle contraction with neat sketches.
Enhanced Solution:



SLIDING FILAMENT THEORY:
The sliding filament theory explains that muscle contraction occurs through the **sliding of thin filaments (actin) over thick filaments (myosin)** without the filaments themselves shortening.
STRUCTURAL COMPONENTS:
Sarcomere structure:
I-band: Contains only actin filaments (light band)
A-band: Contains both actin and myosin filaments (dark band)
H-zone: Contains only myosin filaments (within A-band)
Z-line: Attachment point for actin filaments
M-line: Center of myosin filaments
Protein components:
Actin: Thin filaments with binding sites for myosin

Myosin: Thick filaments with globular heads containing ATPase
Tropomyosin: Regulatory protein covering myosin binding sites
Troponin: Calcium-binding regulatory protein complex
MECHANISM OF CONTRACTION:
Step 1: Excitation-Contraction Coupling
Neural signal reaches neuromuscular junction
Acetylcholine released, creating action potential
Action potential spreads along sarcolemma and T-tubules
Sarcoplasmic reticulum releases Ca^{2+} ions
Step 2: Calcium Binding
Ca^{2+} binds to troponin C
Conformational change moves tropomyosin
Myosin binding sites on actin become exposed
Step 3: Cross-Bridge Formation
Myosin heads bind to actin forming cross-bridges
ATP provides energy for myosin head cocking
Step 4: Power Stroke
Myosin heads pivot, pulling actin filaments
ADP and Pi released during power stroke
Actin slides toward center of sarcomere
Step 5: Cross-Bridge Breaking
New ATP binds to myosin head
Cross-bridge breaks, myosin head detaches
ATP hydrolysis re-cocks myosin head
Step 6: Cycle Continues
Process repeats as long as Ca^{2+} and ATP are available
Multiple cross-bridges work asynchronously
CHANGES DURING CONTRACTION:
I-band: Shortens (actin slides over myosin)
A-band: Length remains constant
H-zone: Shortens or disappears
Sarcomere: Overall length decreases
Z-lines: Move closer together
RELAXATION:
Ca^{2+} pumped back into sarcoplasmic reticulum
Tropomyosin covers myosin binding sites
Cross-bridges cannot form
Muscle returns to resting length
ENERGY REQUIREMENTS:
ATP for contraction: Cross-bridge cycling, Ca^{2+} release

ATP for relaxation: Ca^{2+} pump operation, cross-bridge breaking

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4. How does a muscle shorten during its contraction and return to its original form during relaxation?

Enhanced Solution:

MUSCLE CONTRACTION MECHANISM:

Phase 1: Neural Activation

Signal initiation: Motor neuron fires action potential

Neurotransmitter release: Acetylcholine released at neuromuscular junction

Membrane depolarization: Action potential spreads across sarcolemma

T-tubule conduction: Signal travels deep into muscle fiber

Phase 2: Excitation-Contraction Coupling

Sarcoplasmic reticulum activation: T-tubule signal triggers Ca^{2+} release

Calcium flood: Ca^{2+} concentration rises from 10^{-7}M to 10^{-5}M

Troponin binding: Ca^{2+} binds to troponin C subunit

Conformational change: Troponin complex shifts tropomyosin position

Phase 3: Cross-Bridge Cycle Initiation

Site exposure: Myosin binding sites on actin become available

High-energy state: Myosin heads in cocked position with ADP + Pi

Initial binding: Myosin heads attach to actin (weak binding)

Strong binding: Release of Pi strengthens cross-bridge

Phase 4: Power Stroke and Shortening

Power stroke: Myosin heads pivot 45°, pulling actin filaments

Force generation: Each myosin head generates ~5 piconewtons of force

ADP release: Completes the power stroke

Filament sliding: Actin slides toward sarcomere center

Phase 5: ATP Binding and Detachment

ATP binding: New ATP molecule binds to myosin head

Conformational change: Myosin head releases from actin

ATP hydrolysis: ATP → ADP + Pi, providing energy for re-cocking

Cycle repetition: Process continues while Ca^{2+} and ATP are present

MUSCLE SHORTENING CHARACTERISTICS:

I-band reduction: Decreases as actin slides over myosin

A-band constancy: Myosin length unchanged

H-zone narrowing: Actin filaments overlap more

Overall shortening: Sum of all sarcomere contractions

MUSCLE RELAXATION MECHANISM:

Phase 1: Neural Cessation

Signal termination: Motor neuron stops firing

Acetylcholine breakdown: Acetylcholinesterase degrades neurotransmitter

Membrane repolarization: Sarcolemma returns to resting potential
Phase 2: Calcium Removal
Active transport: Ca^{2+}-ATPase pumps Ca^{2+} back into sarcoplasmic reticulum
Energy requirement: 1 ATP per 2 Ca^{2+} ions transported
Concentration drop: Ca^{2+} levels fall below threshold for troponin binding
Troponin release: Ca^{2+} dissociates from troponin C
Phase 3: Regulatory Protein Reset
Tropomyosin repositioning: Returns to blocking position over binding sites
Myosin binding prevention: Active sites on actin become covered
Cross-bridge inhibition: New cross-bridges cannot form
Phase 4: Passive Lengthening
Elastic recoil: Elastic elements (titin, connective tissue) restore length
External forces: Gravity, antagonist muscles, or external stretch
Sarcomere restoration: Returns to original resting length
Energy independence: Lengthening requires no ATP
ENERGY REQUIREMENTS:
During contraction:
Cross-bridge cycling: ~1 ATP per cycle per myosin head
Calcium release: Minimal ATP for release mechanism
High demand: Rapid ATP consumption during intense activity
During relaxation:
Calcium reuptake: Major ATP consumer during relaxation
Maintenance metabolism: Basal ATP for cellular functions
Recovery processes: ATP for restoring ion gradients
REGULATION AND CONTROL:
All-or-nothing: Individual muscle fibers contract maximally
Graded response: Recruitment of motor units provides force gradation
Frequency modulation: Higher stimulation frequency increases force
Fatigue factors: ATP depletion, lactic acid accumulation limit duration

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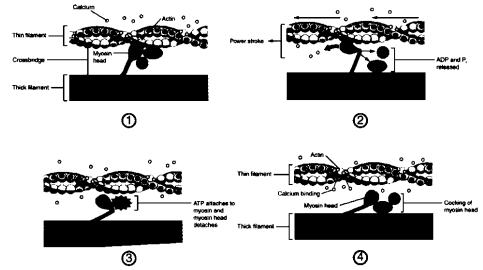
5. Discuss the role of Ca^{2+} ions in muscle contraction. Draw neat sketches to illustrate your answer.
Enhanced Solution:



ROLE OF Ca^{2+} IONS IN MUSCLE CONTRACTION:

CALCIUM STORAGE AND RELEASE:

1. Sarcoplasmic Reticulum (SR):

Structure: Specialized endoplasmic reticulum surrounding myofibrils

Function: Primary Ca^{2+} storage organelle in muscle cells

Concentration: Maintains 10^{-3} M Ca^{2+} inside SR vs 10^{-7} M in sarcoplasm

Release mechanism: Voltage-gated Ca^{2+} channels (ryanodine receptors)

2. T-tubule System:

Structure: Invaginations of sarcolemma penetrating muscle fiber

Function: Conducts action potential deep into fiber

Coupling: Connected to SR through dihydropyridine receptors

Synchronization: Ensures simultaneous Ca^{2+} release throughout fiber

MOLECULAR MECHANISM OF CALCIUM ACTION:

Step 1: Calcium Release

Action potential propagation: Signal travels along T-tubules

Conformational coupling: Dihydropyridine receptors activate ryanodine receptors

Massive release: Ca^{2+} floods from SR into sarcoplasm

Concentration rise: From 10^{-7} M to 10^{-5} M (100-fold increase)

Step 2: Troponin Binding

Troponin C: Contains high-affinity Ca^{2+} binding sites

Binding sites: 4 Ca^{2+} binding sites per troponin molecule

Cooperativity: Ca^{2+} binding increases affinity for subsequent Ca^{2+}

Conformational change: Ca^{2+}-troponin complex alters shape

Step 3: Tropomyosin Movement

Regulatory position: Tropomyosin normally blocks myosin binding sites

Ca^{2+}-induced shift: Troponin complex moves tropomyosin

Site exposure: Myosin binding sites on actin become accessible

Cooperative units: Each tropomyosin regulates 7 actin monomers

Step 4: Cross-Bridge Formation

Myosin binding: Strong cross-bridges form with exposed actin sites

ATPase activation: Ca^{2+} enhances myosin ATPase activity

Force generation: Cross-bridge cycling produces contraction force

Sustained contraction: Continues while Ca^{2+} remains elevated

CALCIUM REMOVAL AND RELAXATION:

1. Active Transport:

SERCA pumps: Sarco-endoplasmic reticulum Ca^{2+}-ATPase

Energy requirement: 1 ATP per 2 Ca^{2+} ions transported

Rate: Can lower Ca^{2+} concentration within milliseconds

Regulation: Controlled by phospholamban

2. Calcium Buffering:

Calsequestrin: Ca^{2+} binding protein inside SR

Parvalbumin: Cytoplasmic Ca^{2+} buffer (in fast-twitch fibers)
Calmodulin: Multifunctional Ca^{2+} binding protein
Function: Prevents excessive free Ca^{2+} levels
CALCIUM SENSITIVITY AND REGULATION:
Factors affecting Ca^{2+} sensitivity:
pH: Acidosis decreases Ca^{2+} sensitivity
Mg^{2+}: Competes with Ca^{2+} for binding sites
Phosphorylation: Troponin I phosphorylation decreases Ca^{2+} sensitivity
Temperature: Higher temperature increases sensitivity
Disease states:
Malignant hyperthermia: Uncontrolled Ca^{2+} release
Muscular dystrophy: Altered Ca^{2+} handling
Heart failure: Impaired Ca^{2+} cycling
Tetany: Low extracellular Ca^{2+} affects excitability
QUANTITATIVE ASPECTS:
Calcium dynamics:
Resting [Ca^{2+}]: ~100 nM
Peak [Ca^{2+}]: ~10 µM during contraction
Release rate: 0.1-1 µmol/L per millisecond
Reuptake rate: 90% removed within 100 ms
Stoichiometry:
Binding ratio: 4 Ca^{2+} per troponin complex
Regulatory units: 1 troponin per 7 actin monomers
Cross-bridges: 1 myosin head per actin monomer (when fully activated)

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6. Differentiate between Pectoral and Pelvic girdle.
Enhanced Solution:
COMPREHENSIVE COMPARISON OF PECTORAL AND PELVIC GIRDLES:

Feature	PECTORAL GIRDLE	PELVIC GIRDLE
LOCATION	Shoulder region	Hip region
BONE COMPOSITION	2 bones: Clavicle and Scapula	3 fused bones: Ilium, Ischium, and Pubis
ARTICULATION CAVITY	Glenoid cavity (shallow)	Acetabulum (deep, cup-shaped)
JOINT WITH LIMB	Ball and socket joint with humerus head	Ball and socket joint with femur head
PRIMARY FUNCTION	Forelimb bone articulation	Hindlimb bone articulation

DETAILED STRUCTURAL DIFFERENCES:

PECTORAL GIRDLE:

Anatomical features:

Clavicle (Collar bone):

S-shaped bone

Articulates with sternum medially

Provides horizontal support

Prevents medial displacement of shoulder

Scapula (Shoulder blade):

Triangular flat bone

Contains glenoid cavity

Has acromion process and spine

Highly mobile, not directly attached to axial skeleton

Functional characteristics:

Mobility priority: Designed for maximum range of motion

Stability sacrifice: Less stable due to shallow socket

Weight bearing: Not designed for weight bearing

Range of motion: 360° rotation possible

Muscle attachments: 17 muscles attach to scapula

PELVIC GIRDLE:

Anatomical features:

Ilium:

Largest, upper portion

Contains iliac crest and fossa

Articulates with sacrum posteriorly

Ischium:

Lower, posterior portion

Forms sitting bone (ischial tuberosity)

Bears body weight when sitting

Pubis:

Lower, anterior portion

Forms symphysis pubis joint

Completes pelvic ring anteriorly

Functional characteristics:

Stability priority: Designed for maximum stability

Weight bearing: Primary weight-bearing structure

Mobility limitation: Restricted range of motion

Deep socket: Acetabulum covers 40% of femoral head

Pelvic cavity: Forms boundaries of pelvic cavity

COMPARATIVE BIOMECHANICS:

Movement patterns:
Pectoral: Multi-directional, reaching, throwing motions
Pelvic: Weight-bearing, locomotion, postural support
Joint stability:
Shoulder joint: Relies on muscles and ligaments for stability
Hip joint: Inherently stable due to deep socket and strong ligaments
Evolutionary adaptation:
Pectoral: Evolved for manipulation and tool use
Pelvic: Adapted for bipedal locomotion and childbirth
CLINICAL SIGNIFICANCE:
Common injuries:
Shoulder: Dislocations, rotator cuff tears, impingement
Hip: Fractures (especially in elderly), arthritis, labral tears
Gender differences:
Pectoral: Minimal sexual dimorphism
Pelvic: Significant differences for childbirth adaptations
Age-related changes:
Both: Susceptible to arthritis and degenerative changes
Hip: Weight-bearing stress leads to more wear
Shoulder: Overuse injuries more common
FUNCTIONAL INTEGRATION:
Kinetic chain relationships:
Upper extremity: Pectoral girdle → arm → forearm → hand
Lower extremity: Pelvic girdle → thigh → leg → foot
Movement coordination:
Pectoral: Works with cervical and thoracic spine
Pelvic: Integrates with lumbar spine and core muscles
Postural significance:
Pectoral: Affects head and neck posture
Pelvic: Determines overall body alignment and balance