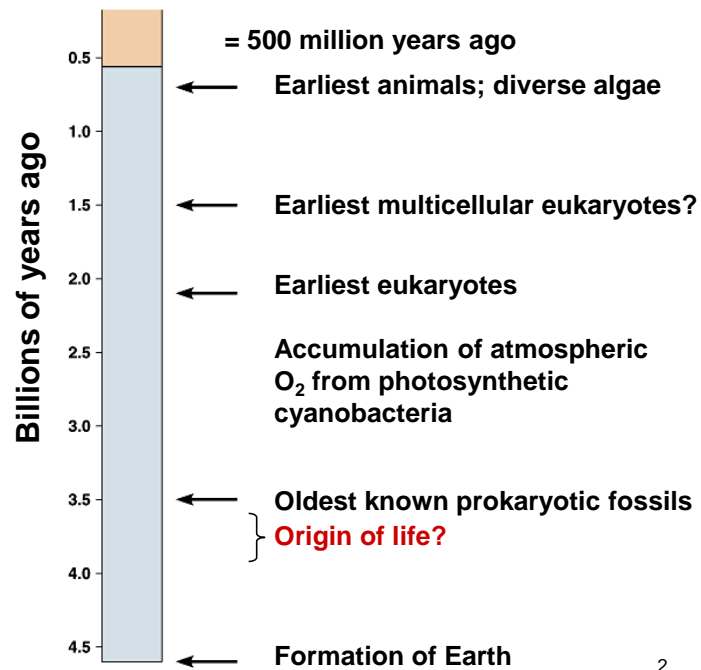




1

Life may  
have  
developed  
from  
nonliving  
materials  
as early as  
3.9 billion  
years ago



2

life => a fact of **continuity**

3

§ **continuity of life**

organism (not immortal)

-> reproduction

-> continuity of life

- **reproduction** is the characteristic that best distinguishes living things from nonliving things

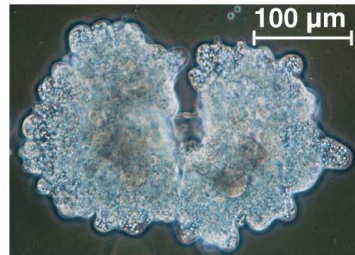
4

- **reproduction**: individual to individual,  
generation to generation  
single-celled organism:  
from 1 cell to 2 cells via **cell division**  
-> reproduction

C



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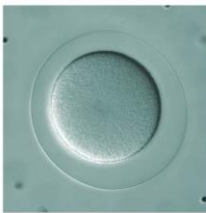
(a) Reproduction

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5

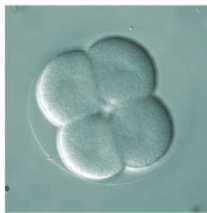
multicellular organism:  
e.g., human body, 100 trillion cells  
zygote -> **cell divisions** -> growth -> **reproduction**

-> **cell division is the basis of reproduction**



(a) Fertilized egg

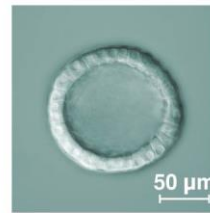
© 2014 Pearson Education, Inc.



(b) Four-cell stage

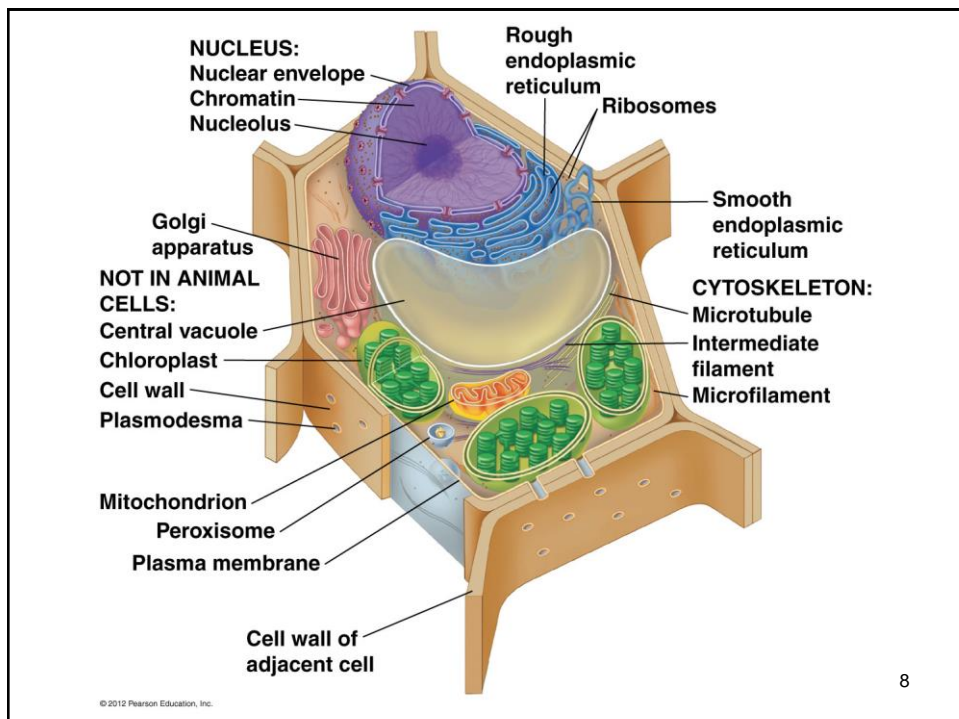
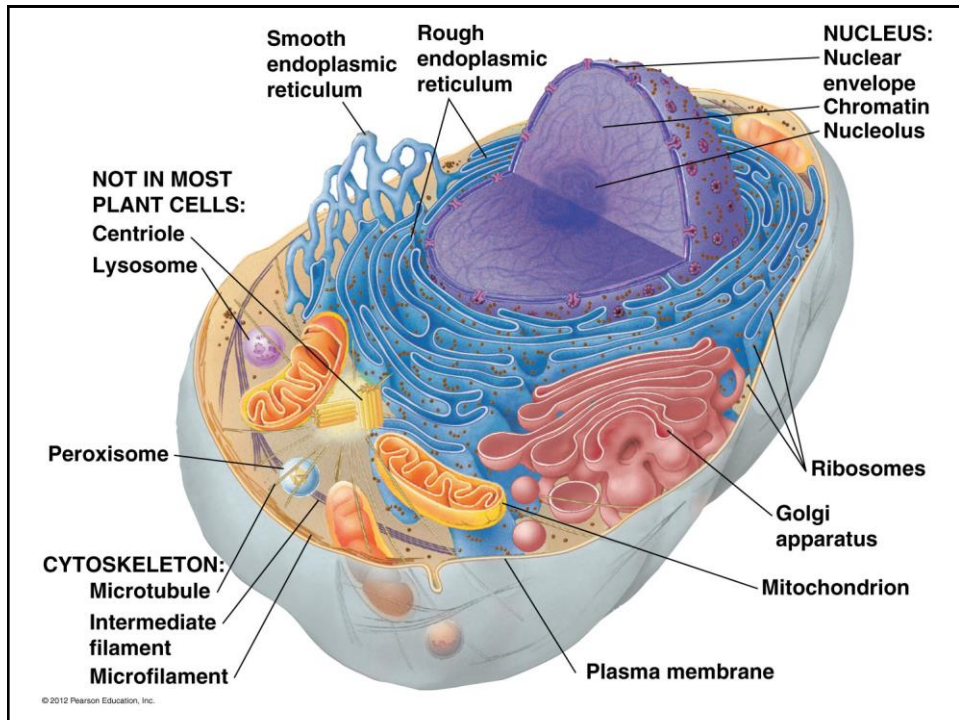


(c) Early blastula



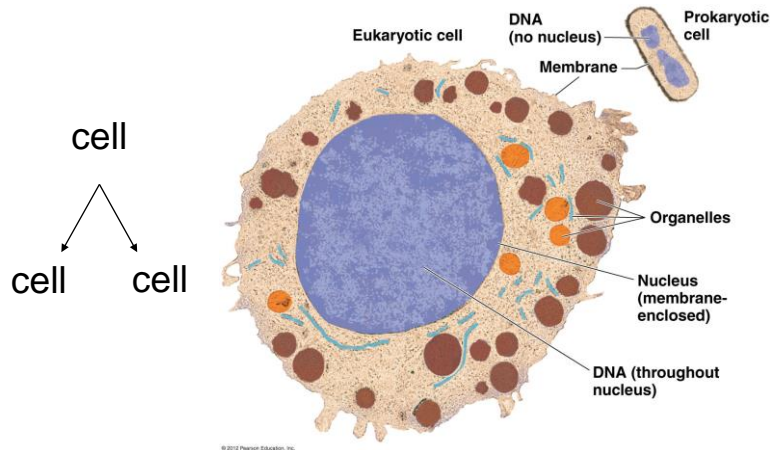
(d) Later blastula

6



## I. Cell division

the process to distribute exact replicas of the **genetic information (material)**, and other stuff, into daughter cells



9

## I. Cell division

the process to distribute exact replicas of the **genetic information (material)**, and other stuff, into daughter cells

### 1). DNA: the genetic material

1 DNA

-> replication 複製

-> 2 DNA , 1 in each daughter cells

DNA molecules



}

2). chromosome:

the structure carrying DNA

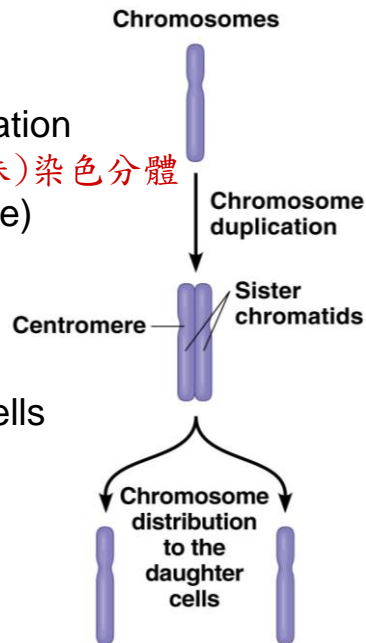
1 chromosome -> duplication

-> 2 **sister chromatids** (姊妹)染色分體  
(1 duplicated chromosome)

-> separation

-> 2 chromosomes,  
1 in each daughter cells

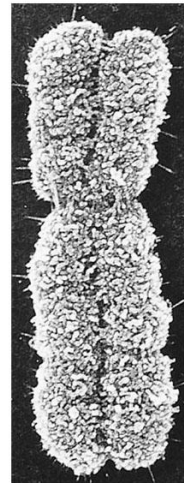
3). 1 cell -> cell division -> 2 cells



2). chromosome:

the structure carrying DNA

2 **sister chromatids** (姊妹)染色分體  
(1 duplicated chromosome)



§ chromosome –  
the center of cell division

two major events in cell divisions

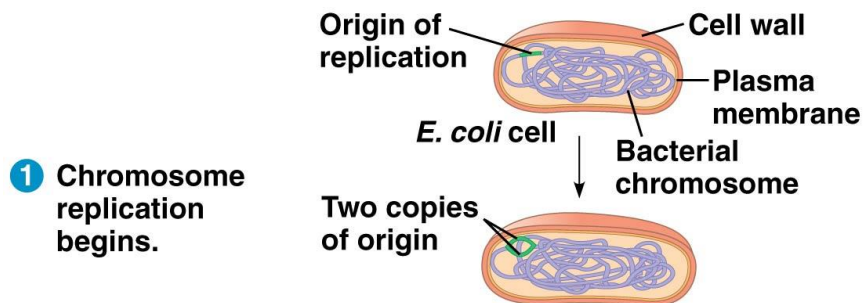
- **accurate duplication of chromosomes**  
精準複製染色體 (DNA)
- **faithful segregation of sister chromatids**  
正確分配姊妹染色分體

13

4). prokaryote: bacteria

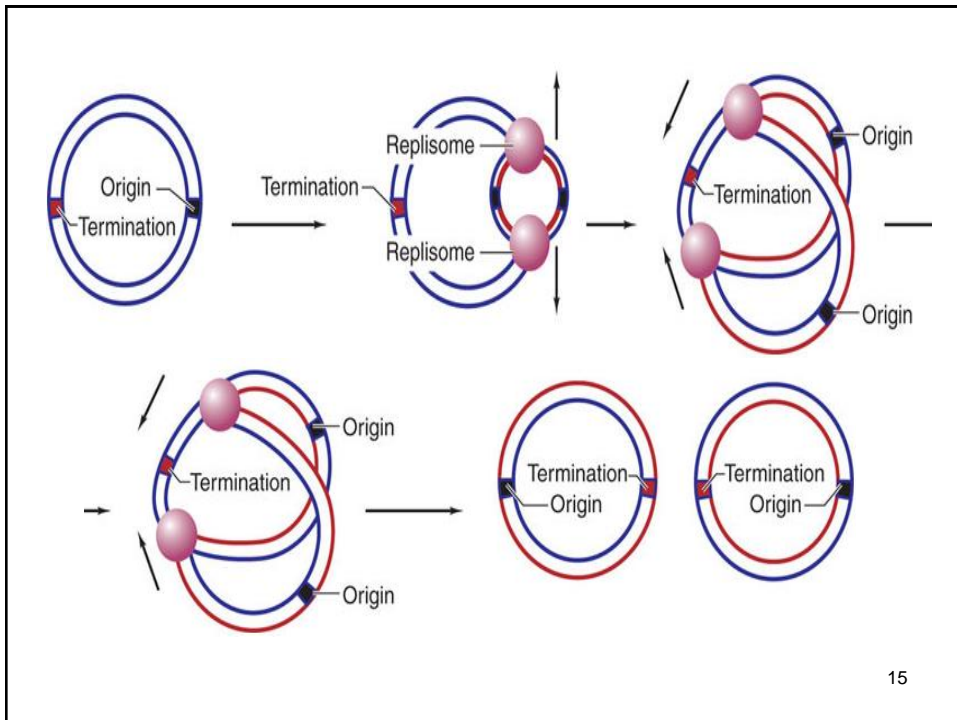
- single long, circular chromosome (500X cell length)
- cell division:

DNA replication begins at the **origin of replication**  
bi-directionally around the circular DNA



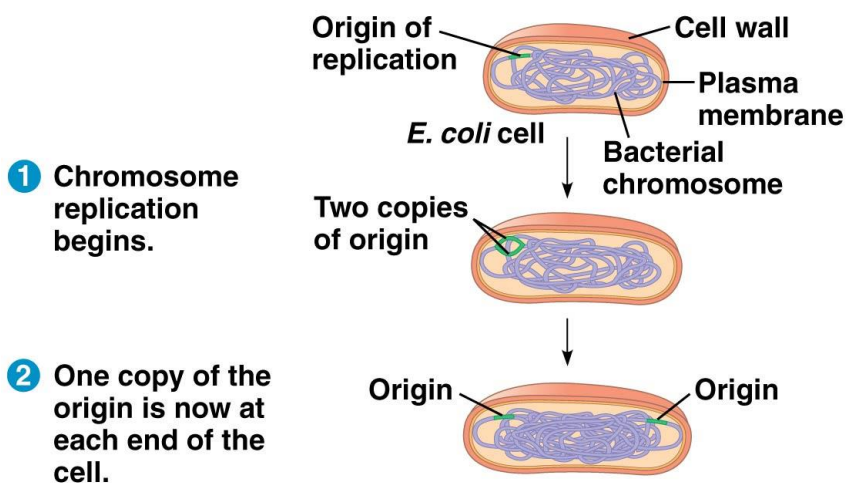
14





#### 4). prokaryote: bacteria

-> cell growth and active partition of chromosomes at the same time



16



#### 4). prokaryote: bacteria

-> new plasma membrane and cell wall grow inward, through the action of tubulin-like and actin-like proteins

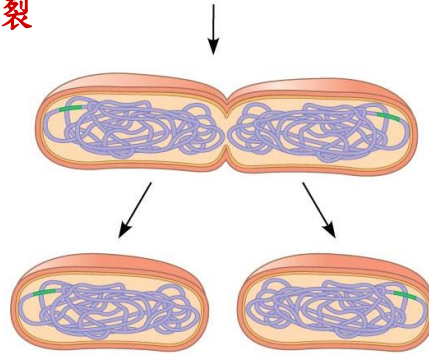
-> **septum** formation-> divides into two cells

=> **binary fission** 二分裂

**3** Replication finishes.

**4** Two daughter cells result.

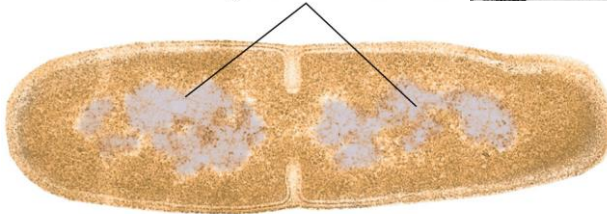
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17

binary fission

Prokaryotic chromosomes



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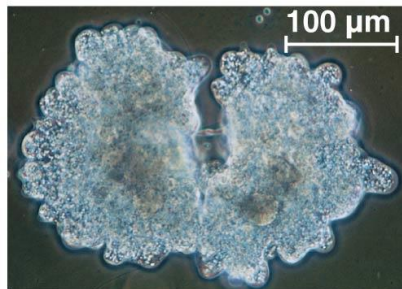
18

## binary fission

a method of **asexual reproduction** for single-celled organisms

in prokaryote, binary fission does not involve mitosis

in single-celled eukaryotes that undergo binary fission, mitosis is part of the process



**(a) Reproduction**

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19

## budding reproduction



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20

## 5). cell division in eukaryote

- more complicated

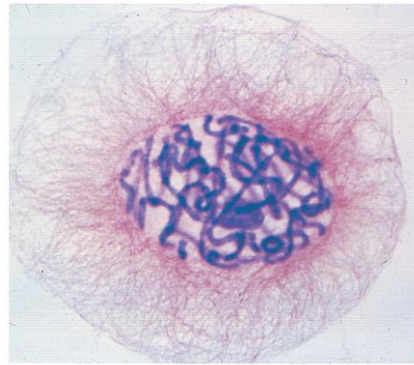
§ a number of distinct chromosomes

§ long chromosomes (DNA) -> packing

§ special apparatus for  
chromosome separation

§ sequence of events

-> cell cycle



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## 5). cell division in eukaryote

### a. a number of distinct chromosomes

Group	Total Number of Chromosomes
<b>F U N G I</b>	
<i>Neurospora</i> (haploid)	7
<i>Saccharomyces</i> (a yeast)	16
<b>I N S E C T S</b>	
Mosquito	6
<i>Drosophila</i>	8
Honeybee	diploid females 32, haploid males 16
Silkworm	56

- each species has a characteristic number of chromosomes

## VERTEBRATES

Opossum	負鼠	22
Frog		26
Mouse		40
Human		46
Chimpanzee		48
Horse		64
Chicken		78
Dog		78

23

## PLANTS

<i>Haplopappus gracilis</i>	纖細單冠菊	2
Garden pea		14
Corn		20
Bread wheat		42
Sugarcane		80
Horsetail	木賊	216
Adder's tongue fern	蛇舌蕨 / 瓶爾小草	1262

24

§ long chromosomes (DNA) -> packing



Figure 8-2a  
Biology of Plants, Seventh Edition  
© 2005 W.H. Freeman and Company

Wake-robin  
北美大花地百合

25

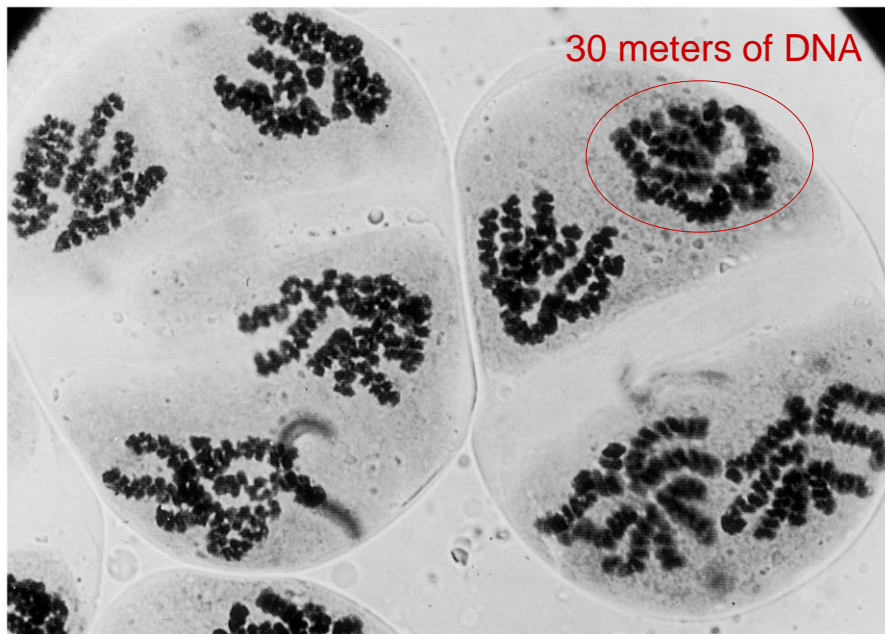


Figure 8-2b  
Biology of Plants, Seventh Edition  
© 2005 W.H. Freeman and Company



## b. complex structure of chromosomes

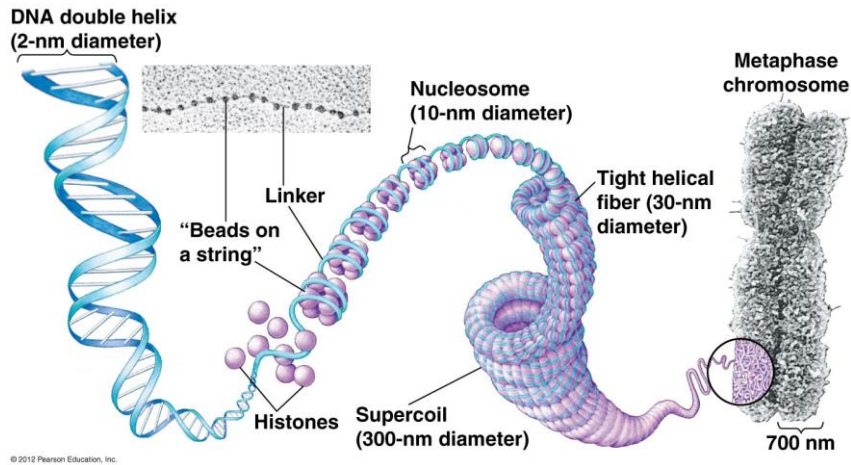
C

- **diffused chromosome**

-> packing, folding, condensation

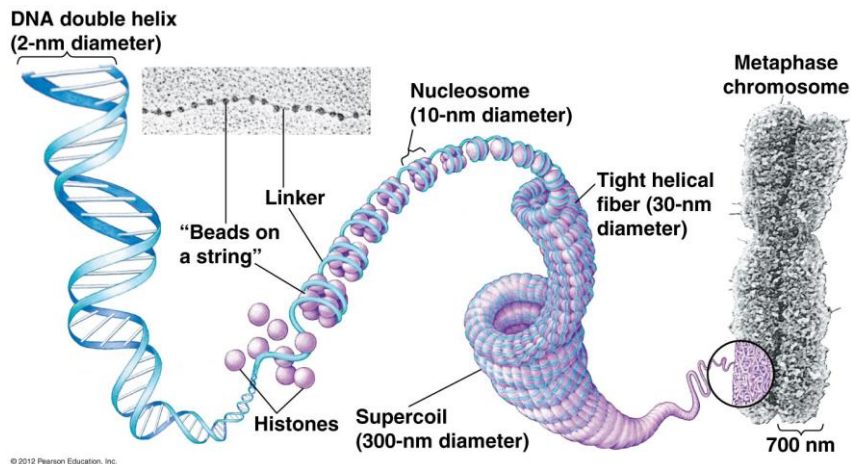
-> **visible chromosome**

Fig.11.2



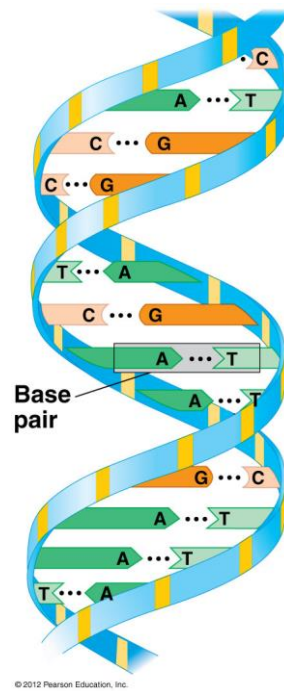
- **chromatin** for complex, components  
**chromosome** for unit, structure

Fig.11.2



DNA, two strands, double helix  
 base pairing between two strands  
 $A=T$   $G=C$

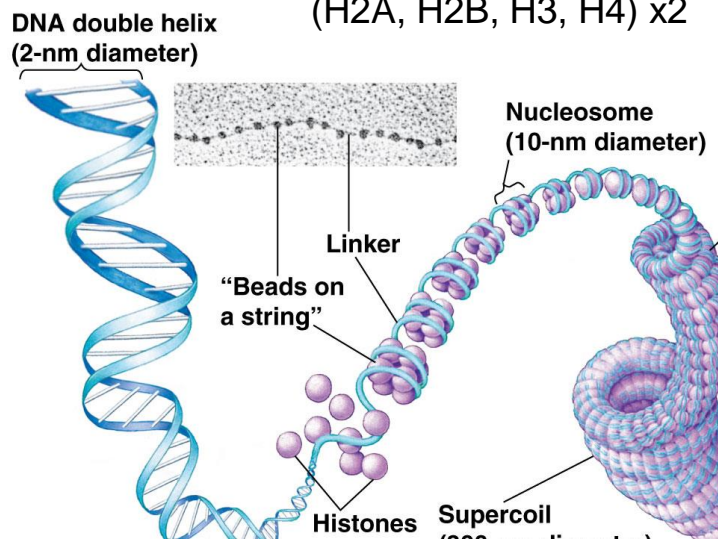
- measurement unit:  
 bp (base pair), kb



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**nucleosome:** 核小體

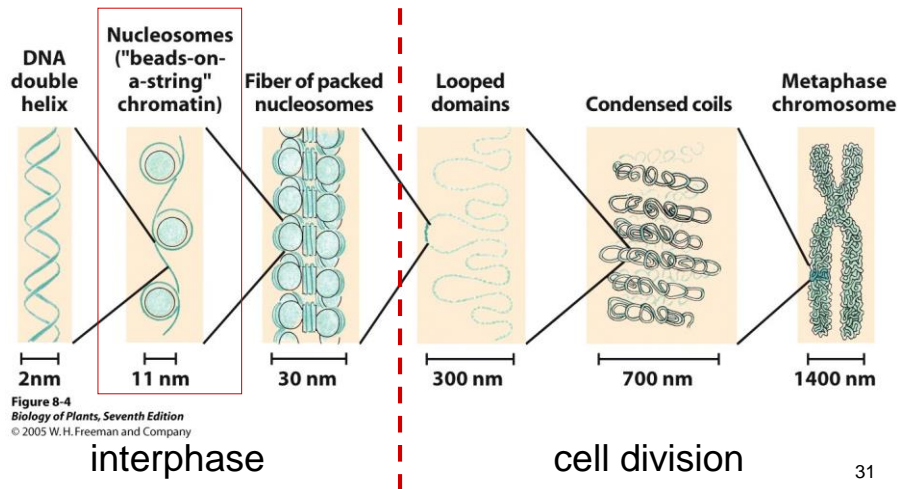
200 bp DNA + a core of 8 histone proteins 組蛋白  
 (H2A, H2B, H3, H4) x2



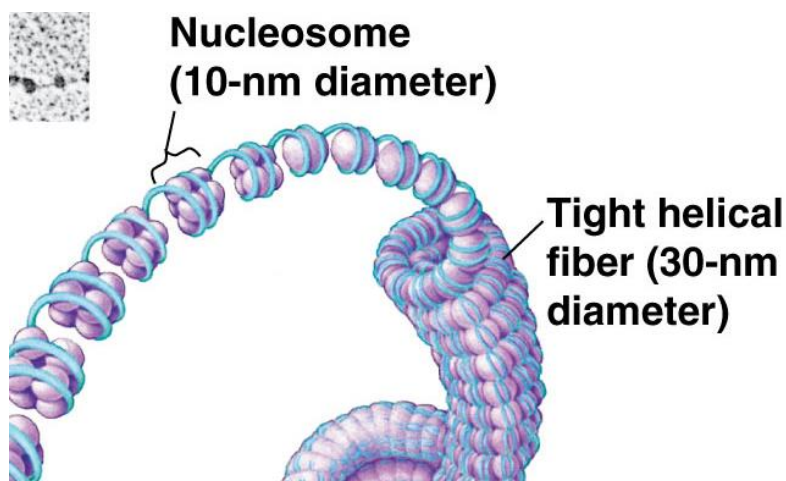
30



**nucleosome** : the basic unit for DNA packing  
 (nucleosome-spacer DNA)<sub>n</sub>  
 -> a string of beads (beads on a string)

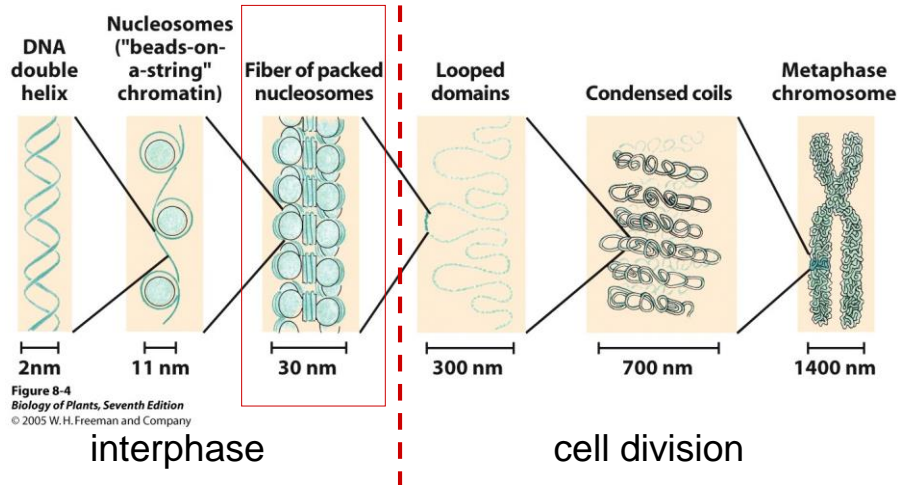


=> a string of beads  
 -> folding -> 30 nm **fiber** at interphase



=> a string of beads

-> folding -> 30 nm **fiber** at interphase

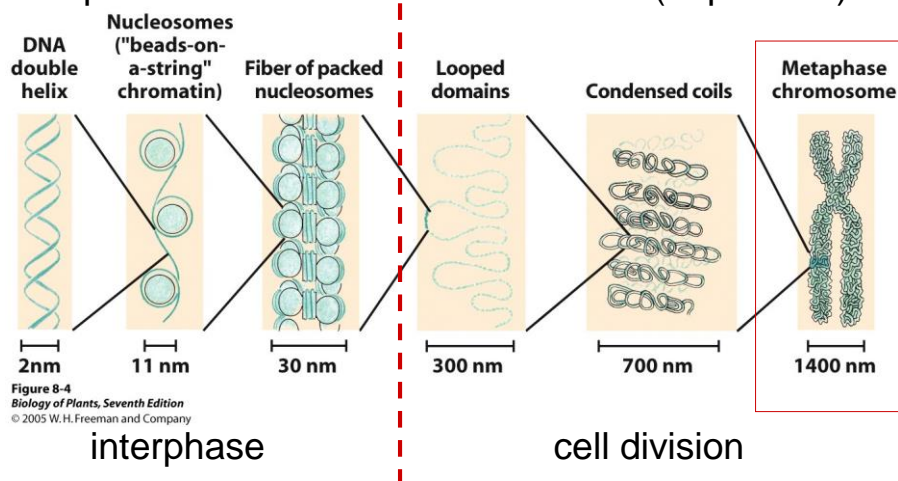


33

30 nm fiber

-> more folding, loop and condensation w/ other proteins

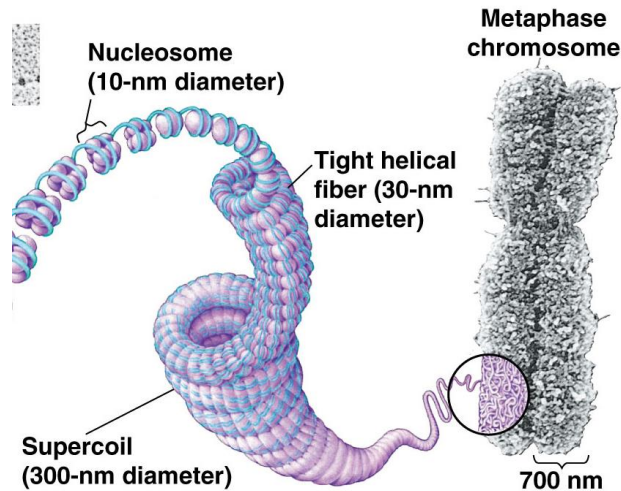
-> chromosome (duplicated)



34

30 nm fiber

-> more folding, loop and condensation w/ other proteins -> chromosome (duplicated)

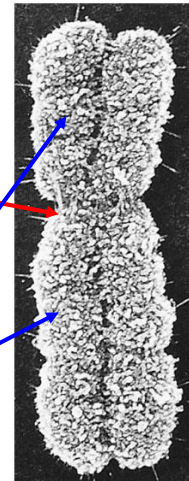


35

a pair of **sister chromatids**  
duplicated chromosomes before  
separation

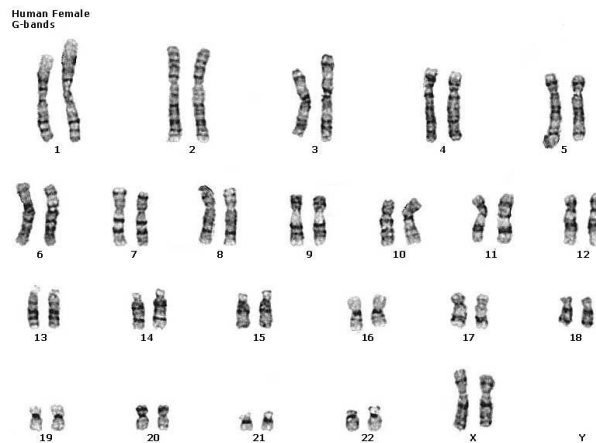
**centromere** 中節: (cytology definition)  
“narrow waist” on duplicated  
chromosomes; the region where two  
sister chromatids are held together

chromosome arms



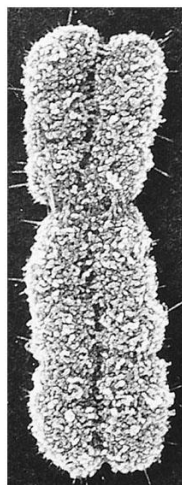
36

- chromosomes vary in size, location of the centromere
- > array of an individual's chromosomes  
=> **karyotype** (核型)



37

What?      How?      Why?

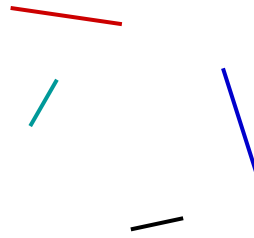


38

§ in mitosis and meiosis

Q: How to distribute each pair of sister chromatids into the two daughter cells?

$2n = 4$ , 複製前



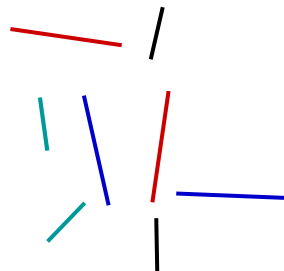
39

§ in mitosis and meiosis

Q: How to distribute each pair of sister chromatids into the two daughter cells?

如何分配？

$2n = 4$ , 複製後

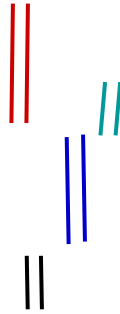


40

§ in mitosis and meiosis

Q: How to distribute each pair of sister chromatids into the two daughter cells?

將要彼此分開的先合在一起，確認分開的partner

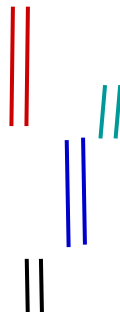


41

§ in mitosis and meiosis

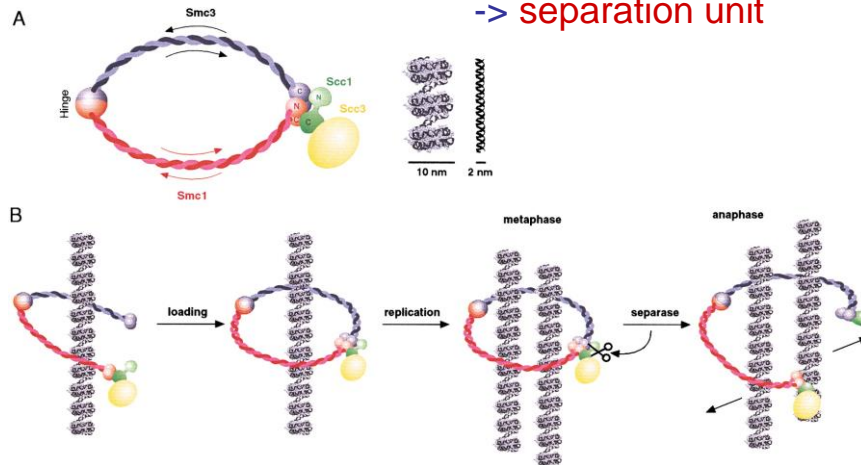
Q: How to distribute each pair of sister chromatids into the two daughter cells?

將要彼此分開的先合在一起，How?



42

sister chromatids are held together by  
**cohesin complex** -> **sister chromatid cohesion**  
 -> **separation unit**



43

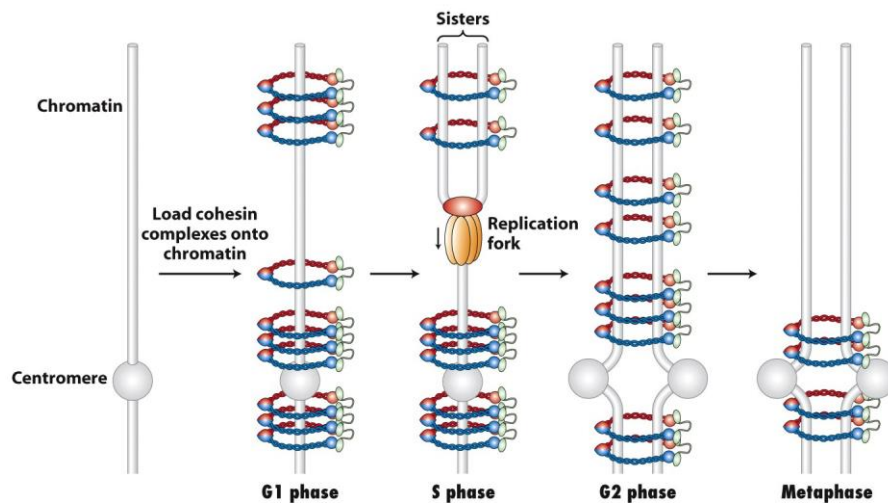
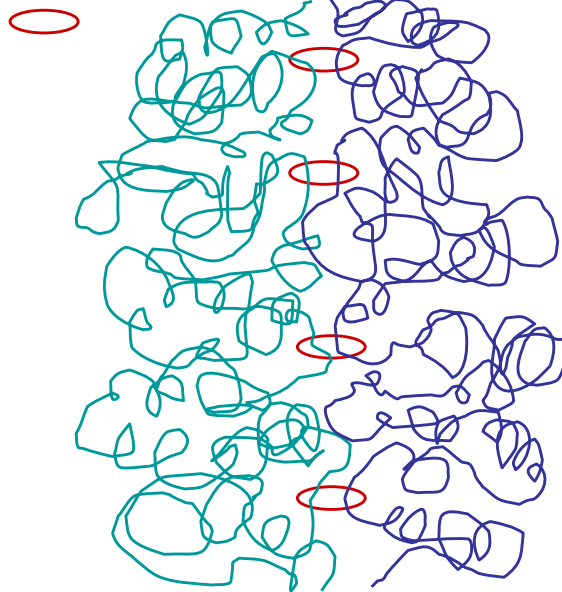


Figure 20-21  
 Molecular Cell Biology, Sixth Edition  
 © 2008 W. H. Freeman and Company

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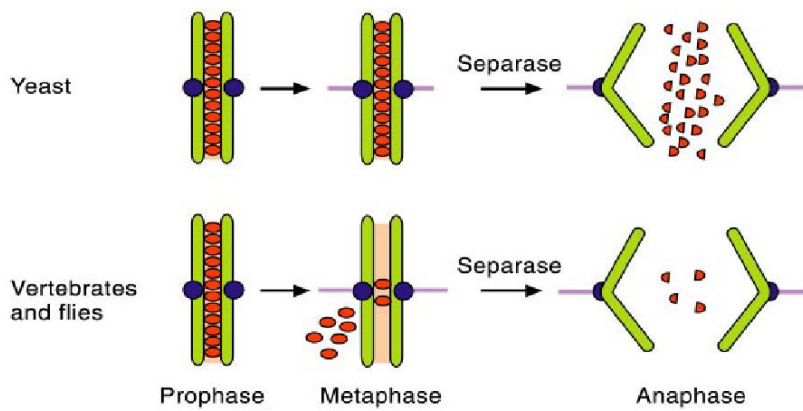


cohesin complex

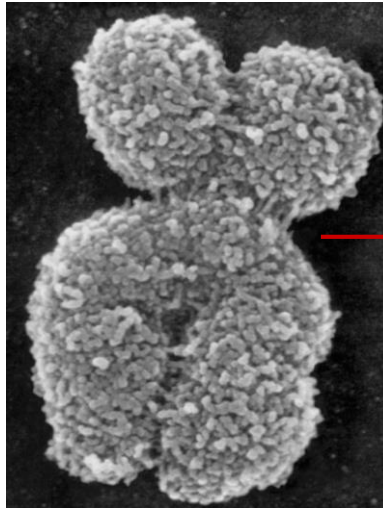


45

### A. Mitosis



46



中節

Molecular Cell Biology, Lodish et al.<sup>47</sup>

§ in mitosis and meiosis

Q: How to distribute each pair of sister chromatids into the two daughter cells?

如何將每一對姊妹染色分體都正確分開(配)?

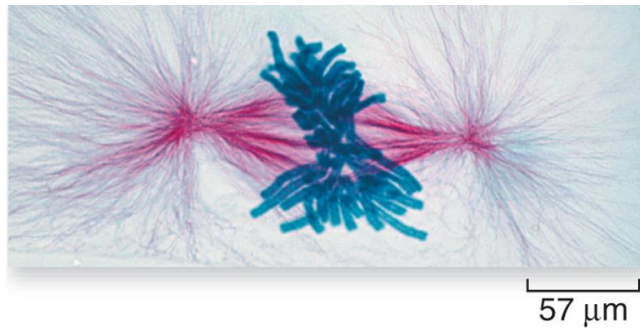


48

c. special apparatus:

**mitotic spindle**: bundle of microtubules  
-> separating chromosomes

**MTOC - microtubule organization center**,  
in animals, centrosome (with centriole )



© Andrew S. Bajer/University of Oregon

Fig.10.12 49

**centromere**: a DNA region that binds specific  
中節 proteins to form **kinetochore** 著絲點  
(特定DNA序列) -> attachment site for microtubules

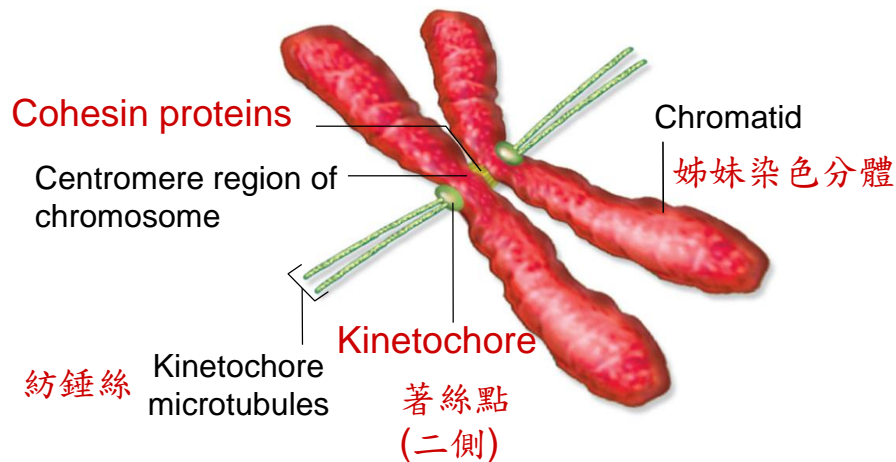


Fig.10.9

50

centromere: a DNA region that binds specific proteins to form kinetochore  
 -> attachment site for microtubules

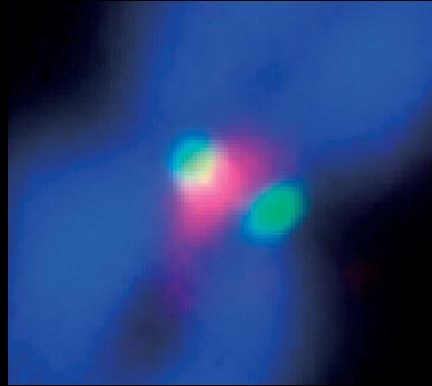
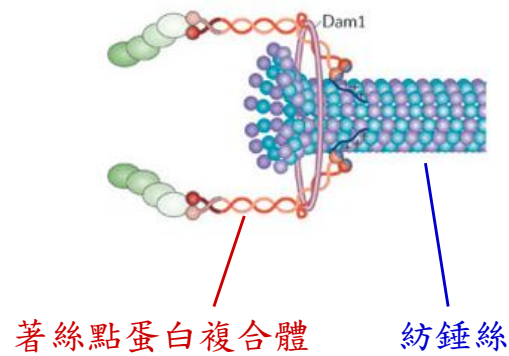


Fig.10.10



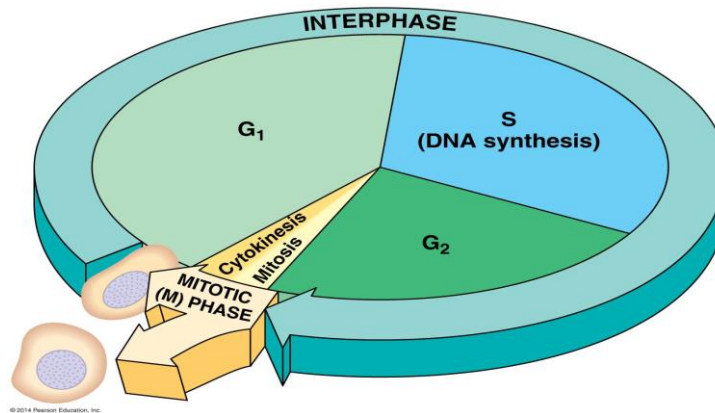
Lampert 2011, Nature Rev MCB

d. orderly, regulated sequence of events

-> cell (division) cycle 細胞週期

the division process:

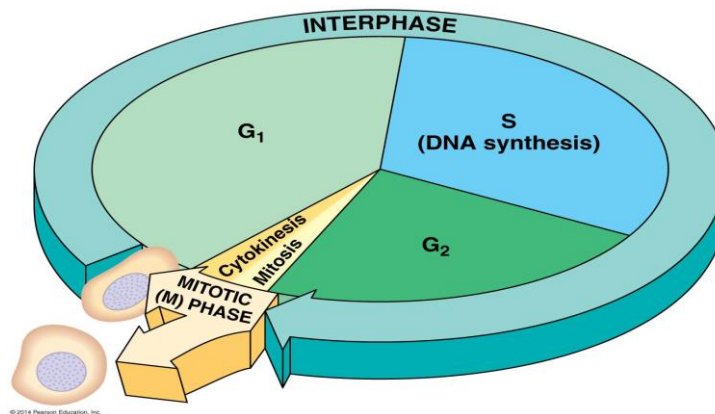
chromosome duplication + **mitosis** + cytokinesis



53

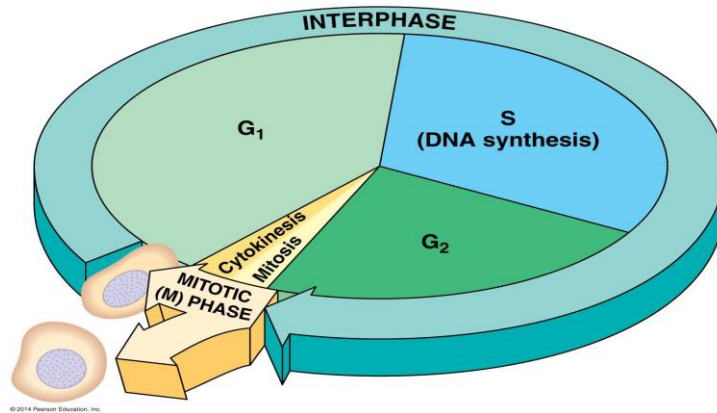
1). interphase 間期

2). M (mitotic ) phase 分裂期



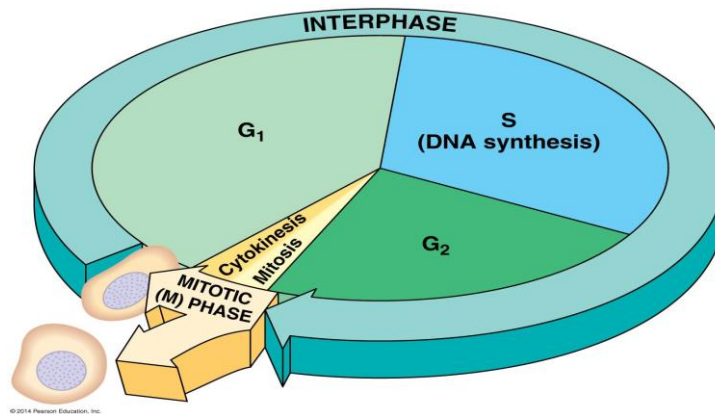
54

- 1). **interphase** , most of the time of cell cycle
  - a. **G<sub>1</sub>(gap)** - increase supply, grow in size, produce organelles, etc.
  - b. **S (synthesis)** - DNA replication, MTOC duplication
  - c. **G<sub>2</sub> (gap)** - prepare for mitosis



55

- 2). **M (mitotic ) phase**
  - a. **mitosis 有絲分裂** - chromosome separation
  - b. **cytokinesis** - division of cytoplasm



56

### III. Cell cycle :

the orderly sequence of events by which a cell duplicates its content and divides into two cells

time: hours to days

§ compare **cell cycle** to **life cycle**:

sequence of events from adults to adults

57

### IV. Mitosis 有絲分裂

1). stages:

prophase 前

**prometaphase** 前中

metaphase 中

anaphase 後

telophase 末

58

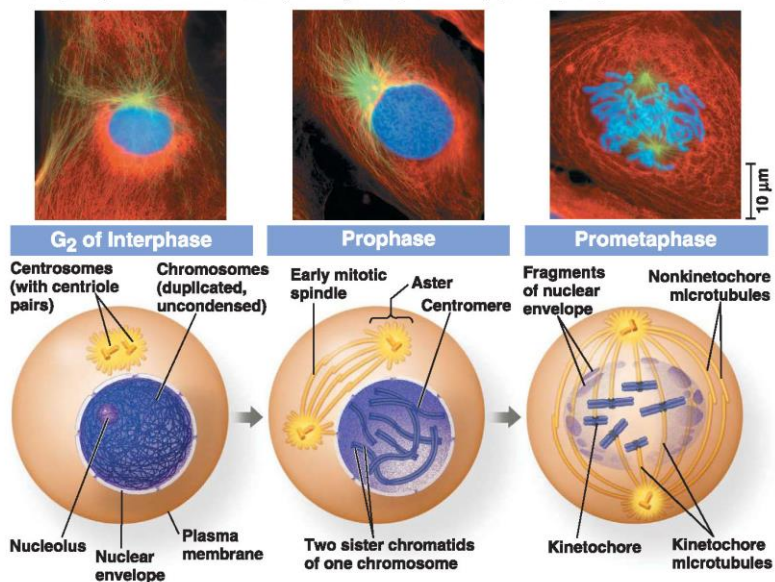


## 2). landmarks:

chromosome  
MTOC or centrosome  
mitotic spindle  
nuclear envelope  
nucleolus

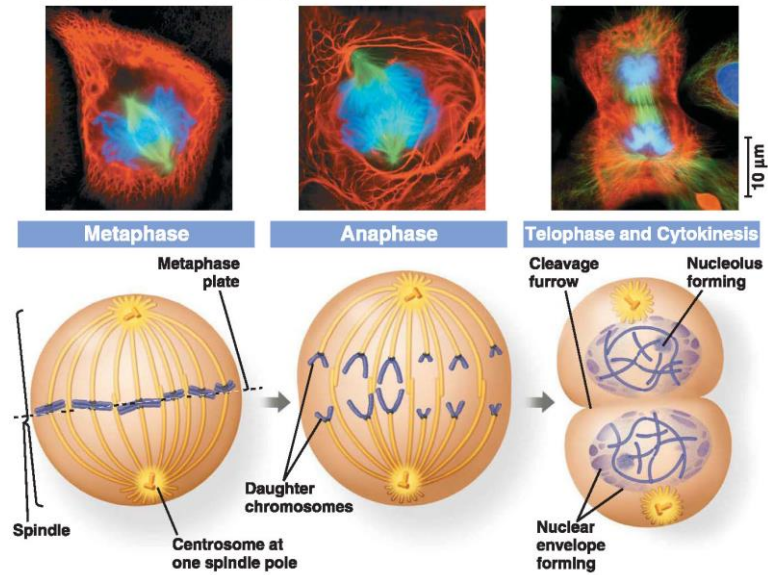
59

Figure 12.7a Exploring mitosis in an animal cell (part 1: G<sub>2</sub> of interphase through prometaphase)



Biology: A Global Approach, 11e, Global Edition, Campbell, Urry, Cain, Wasserman, Minorsky, Reece, © 2018 Pearson Education Ltd.

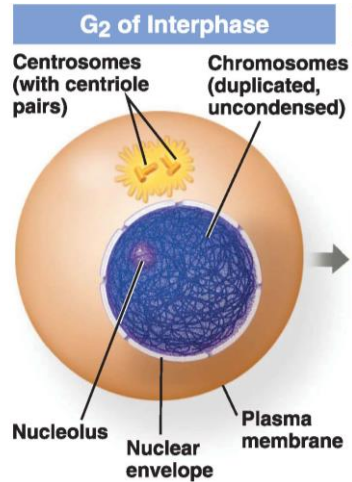
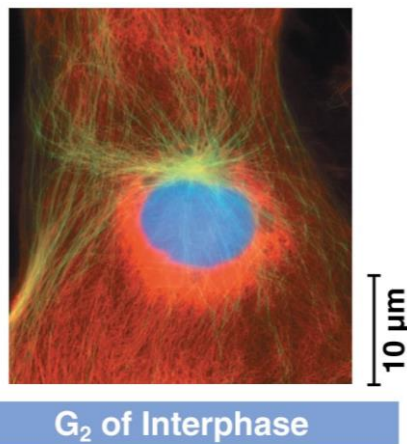
**Figure 12.7b** Exploring mitosis in an animal cell (part 2: metaphase through cytokinesis)



*Biology: A Global Approach, 11e, Global Edition, Campbell, Urry, Cain, Wasserman, Minorsky, Reece, © 2018 Pearson Education Ltd.*

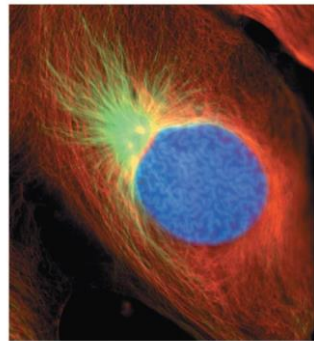
**Figure 8.5-2**

## Interphase (G<sub>2</sub>)



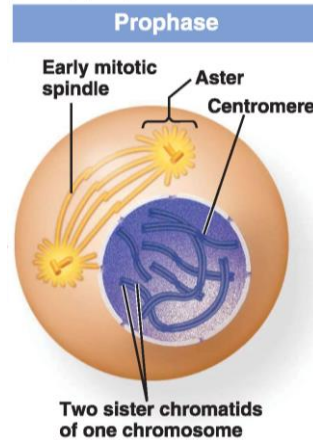
### 3). **prophase:** 前期

- duplicated chromosomes condense -> visible
- nucleolus disappears
- duplicated MTOCs move away from each other
- microtubules grow out from MTOCs -> aster



Prophase

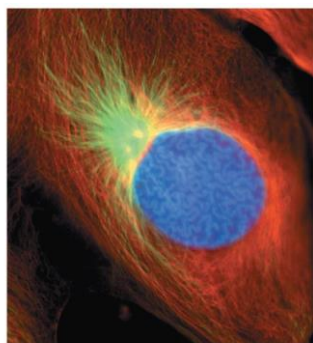
Varian Education, Inc.



63

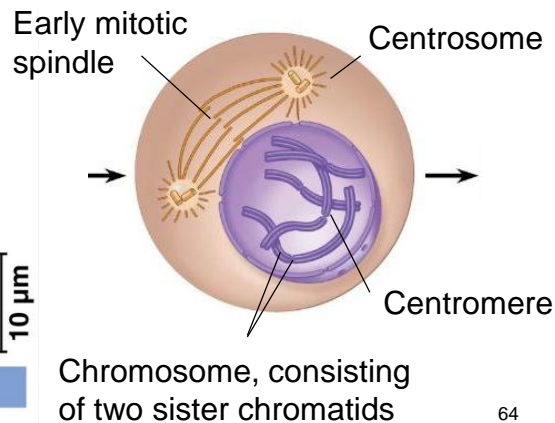
### 3). **prophase:** 前期

- duplicated chromosomes condense -> visible
- nucleolus disappears
- duplicated MTOCs move away from each other
- microtubules grow out from MTOCs



Prophase

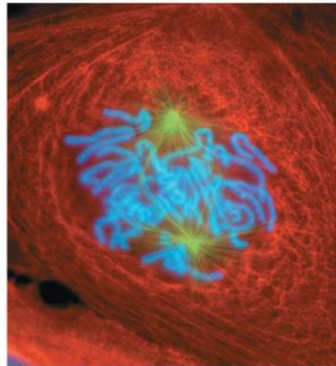
Varian Education, Inc.



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## prometaphase 前中期

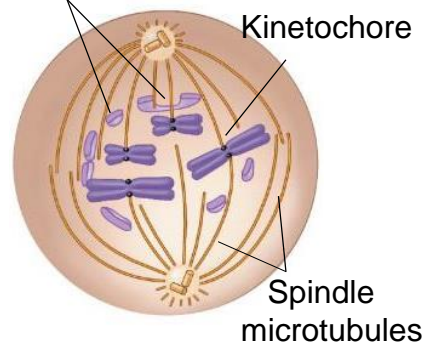
- nuclear envelope breaks down
- the spindle is fully formed
- spindle microtubules attach to kinetochores



Prometaphase

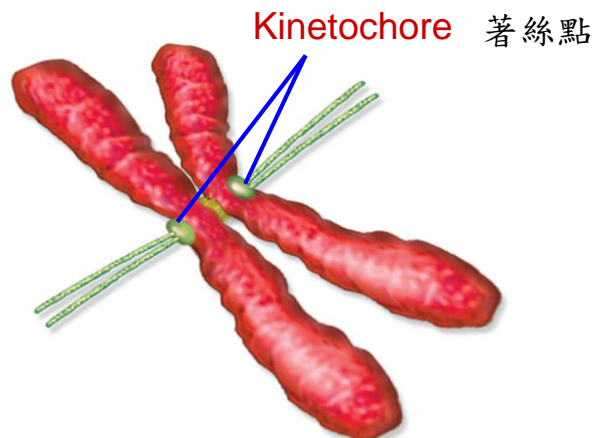
erson Education, Inc.

Fragments of the nuclear envelope



65

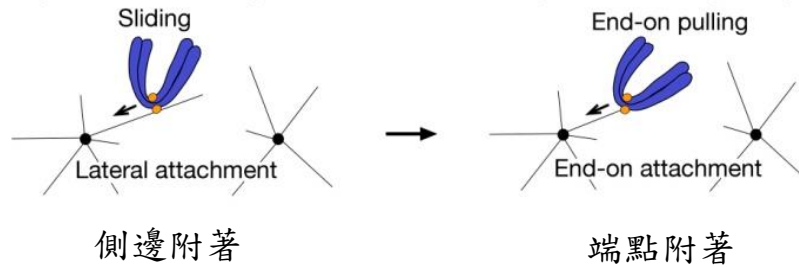
- kinetochores of the two sister chromatids attached to microtubules from the two opposite poles of the spindle => **bipolar attachments** 雙極聯結



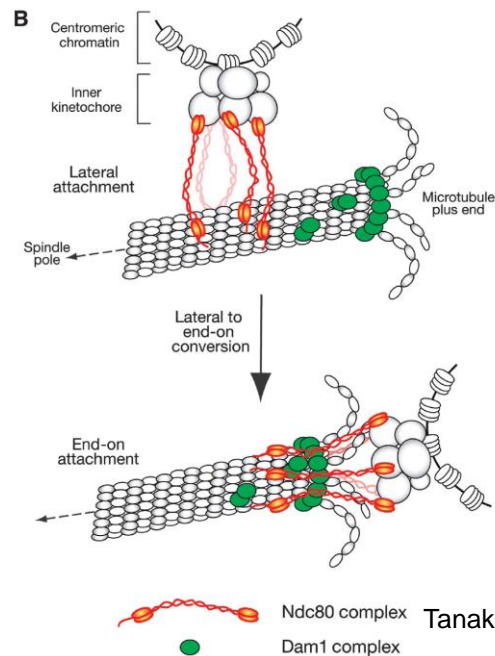
66

## prometaphase 前中期(中期前)

Step 2. Microtubule-dependent kinetochore transport towards a spindle pole

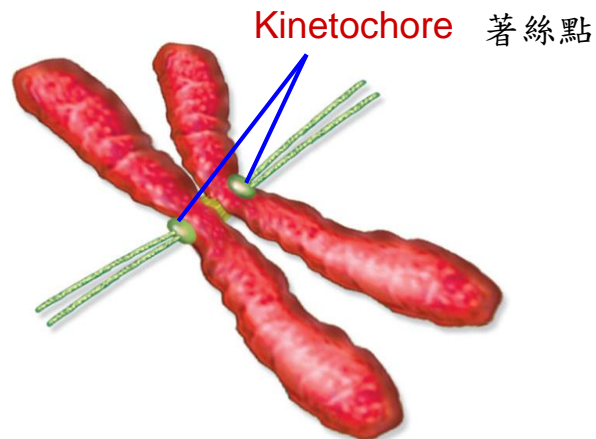


Takana 2010, EMBO J. 67



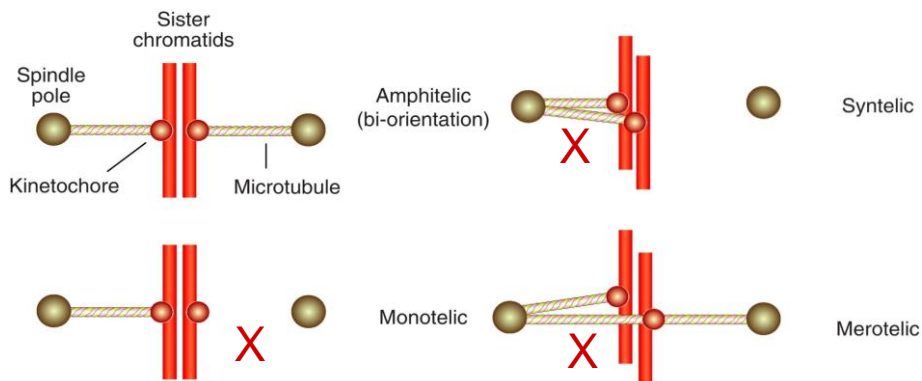
Tanaka, 2010, EMBO J. 68

- kinetochores of the two sister chromatids attached to microtubules from the two opposite poles of the spindle => **bipolar attachments** 雙極聯結



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### unattached or incorrect kinetochore



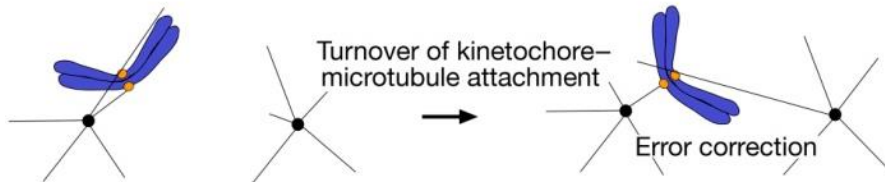
Santaguida, 2009, EMBO J. 70



## prometaphase 前中期(中期前)

error correction -> bipolar pulling (attachment)

Step 3. Interaction of sister kinetochores with microtubules from the same or opposite spindle poles



Takana 2010, EMBO J, 1

1. How to know the attachment is incorrect?
2. How to fix it?



72

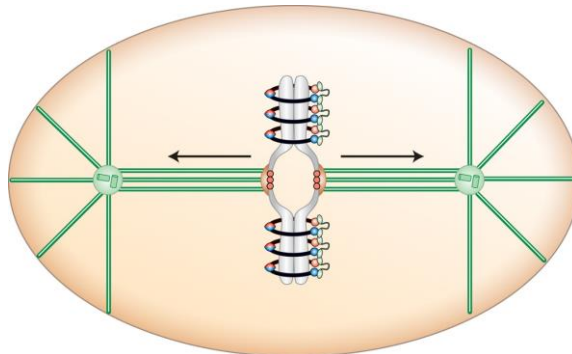


1. How to know the attachment is incorrect?
2. How to fix it?



73

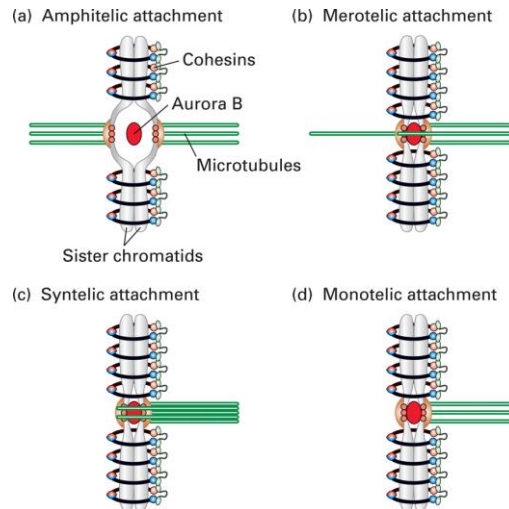
正確附著時，在中節會形成張力 tension



Molecular Cell Biology, Lodish et al. <sup>74</sup>

中節部位有tension則著絲點和紡錘絲的結合穩定  
無tension，著絲點會脫離紡錘絲，進行新的附著

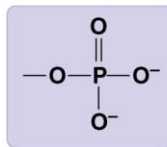
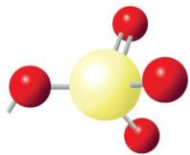
**Aurora B**  
kinase  
磷酸激酶



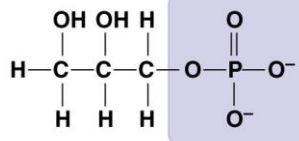
Molecular Cell Biology, Lodish et al.<sup>75</sup>

磷酸基

Phosphate group ( $\text{—OPO}_3^{2-}$ )



Organic phosphate



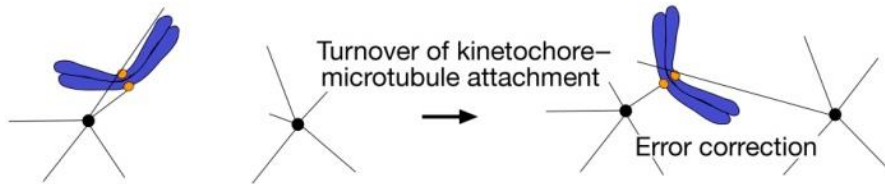
Glycerol phosphate, which takes part in many important chemical reactions in cells

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## prometaphase 前中期(中期前)

error correction -> bipolar pulling (attachment)

Step 3. Interaction of sister kinetochores with microtubules from the same or opposite spindle poles



Takana 2010, EMBO J<sub>7</sub>

